

YEAR BOOK 00/01

2000-2001

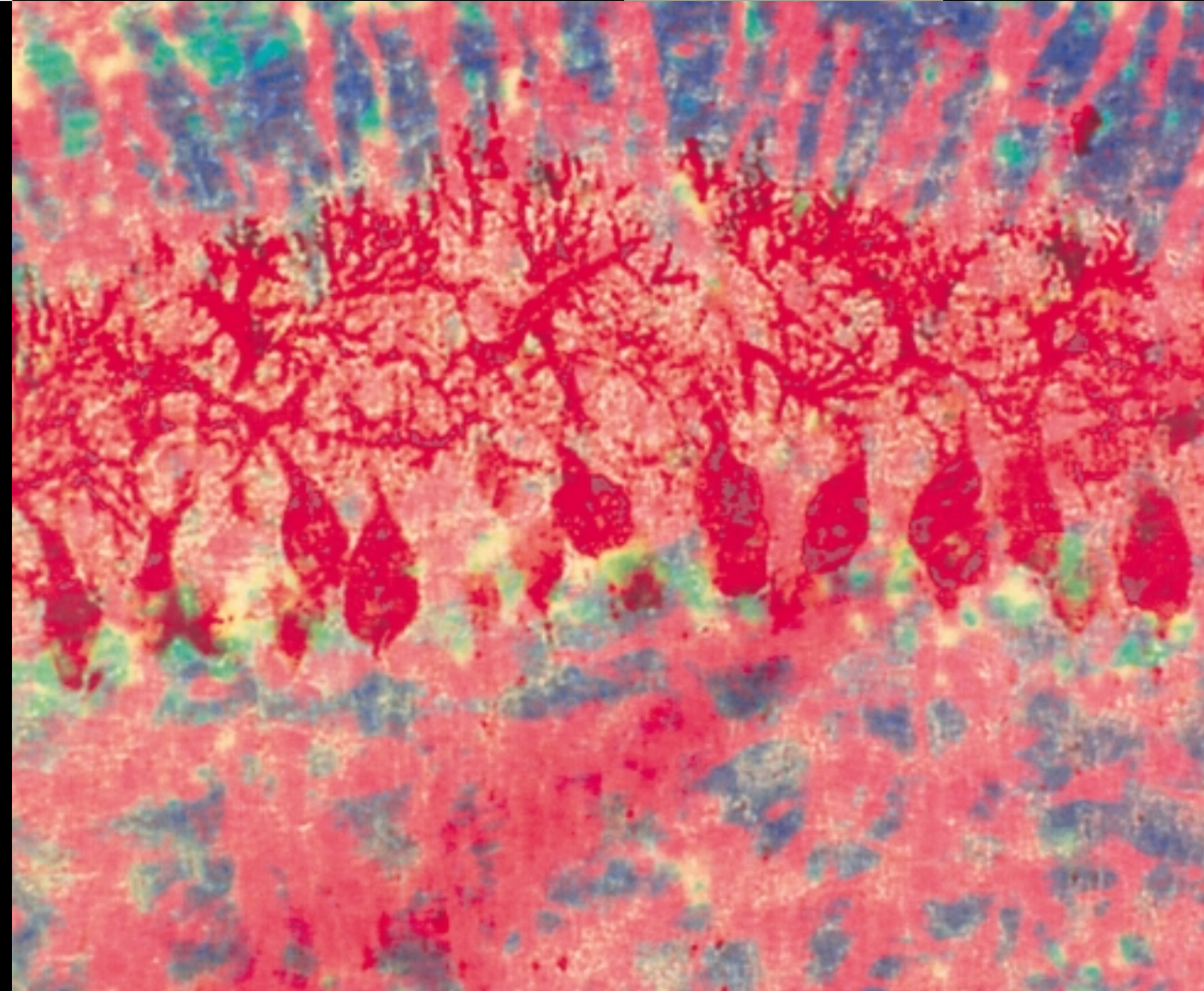
CARNEGIE INSTITUTION OF WASHINGTON

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Opening New Horizons for Scientific Research

YEAR BOOK 00/01

2000-2001



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On the cover: **Above:** This is a simulation of what happens to magnetic metal ions in iron oxide and cobalt oxide as pressure increases. (Courtesy Ronald Cohen, Geophysical Laboratory.)

Below: Chen-Ming Fan uses the mouse in his research on the genetics of development. This is an image of a developing cerebellum in that model organism. (See page 49.)



YearBook 00/01

THE PRESIDENT'S REPORT

July 1, 2000 — June 30, 2001

CARNEGIE INSTITUTION
OF WASHINGTON

ABOUT CARNEGIE

... TO ENCOURAGE, IN THE BROADEST AND MOST LIBERAL MANNER, INVESTIGATION, RESEARCH, AND DISCOVERY, AND THE APPLICATION OF KNOWLEDGE TO THE IMPROVEMENT OF MANKIND ...

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A supplemental electronic version of the Year Book is accessible via the Internet at **www.CarnegieInstitution.org/yearbook.html**. The electronic version includes individual essays by Carnegie scientists in addition to the material in this print publication.

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"IT SEEMS CLEAR THAT IN THE IDEAL RESEARCH GROUP OF THIS SORT NOT ONLY ARE THE UNFETTERED FREEDOM AND INDIVIDUALITY OF EACH OF ITS KEY MEMBERS CAREFULLY GUARDED AS A FACTOR VITAL TO SUCCESS BUT ALSO A MAJOR FUNCTION OF THE GROUP IS INDEED TO PROVIDE AN ENVIRONMENT WHERE SUCH INDIVIDUALITY WILL BE ENHANCED AND STIMULATED TO THE UTMOST..."

CARYL P. HASKINS, CARNEGIE YEAR BOOK 63/64

The Carnegie Institution's Year Book, like that of many other institutions, appears months after the June 30 end of the fiscal year mentioned in its title. By the time this volume is distributed, it will be 2002 and we will be celebrating the institution's centennial. On January 29, 1902, the initial trustees met to begin the bewildering task of building a research institution. All of them were important and distinguished men chosen by Andrew Carnegie as stewards of his \$10-million establishing grant. They had no map, no precedents to go by. Most of them were neither scientists nor scholars. But they began boldly, seeking advice from people engaged in research. Now, a century later, the institution they set on course must consider its past and present and look equally boldly into its future. There is still no map, and there are few if any models.

A Remarkable Past

Many extraordinary individuals drew the maps for the Carnegie Institution in the course of its first century. Two of them, former presidents Caryl P. Haskins and James D. Ebert, died last year. Both contributed mightily to our remarkable past and remained influential as trustees long after completing their presidential terms and until they were lost to us. Haskins (Fig. 1) was president from 1956 to 1971. His great scientific passion was reserved for ants, but that passion did not constrain

him. For Caryl, the natural world and the world of human affairs held endless fascination and challenge, and he moved with ease between basic research, applied research, industry, government, and academia. Haskins's bold vision assured the founding of the Las Campanas Observatory. An enduring legacy lies in his graceful yet powerful words about the value of science and scientists to society.

Ebert served as president from 1978 to 1987 after more than 20 years as director of the Department of Embryology. As department director, he



Fig. 1. Caryl Haskins (right), Carnegie president from 1956 to 1971, is shown here in 1994 with former director of the Department of Embryology Donald Brown (left) and the current director of that department, Allan Spradling.



Left: The new Magellan telescopes will be an important component to Carnegie's second century of discovery. This image was taken on February 22, 2001, during the first week of regular observations at the new 6.5-meter Walter Baade telescope at Las Campanas. Most of the bright objects are from our galaxy, but the large red spheres near the center are globular clusters in NGC 5128, the giant elliptical galaxy closest to us. (Courtesy M. Rejkuba, D. Minniti, and F. Courbin.)

realized that the time had come to revolutionize embryology by promoting the fusion of embryology and genetics, a fusion that now defines developmental biology worldwide. Then and later when he was president of the institution, Ebert was instrumental in bringing our first 100 years to a proud ending (Fig. 2). It was he who championed the building of a new, large telescope at Las Campanas and convinced the trustees that modern, co-located laboratories were needed for the Geophysical Laboratory (GL) and the Department of Terrestrial Magnetism (DTM). Jim and Alma Ebert's untimely accidental death this summer took away two of the institution's most loyal, dedicated, and influential friends.

would be to begin a new research direction. But what should it be? The great advances in scientific knowledge during the 20th century have generated more questions about the natural world than our predecessors imagined. Like the first trustees, we needed advice. Between April and October of 1999, trustees, Carnegie department directors, Staff Members, and I posed the question to five multidisciplinary groups of distinguished scientists in Washington, D.C., Cambridge, Pasadena, Palo Alto, and New York. Altogether, 46 people took part in these conversations, which lasted for hours. Like those consulted in 1902, these outstanding people spoke to us of the most advanced and innovative thinking in their own fields. Altogether it was an exhilarating intellectual experience and a rare firsthand glimpse at how accomplished and brilliant scientists see future opportunities.

Certain topics consistently emerged and some were mirrored in written proposals from the Carnegie staff. They included such varying ideas as the early evolution of Earth and life, including the origin of life; the rich and still largely obscure microbial world; genetics and all that follows from knowing the DNA sequence of genomes; higher brain function, including the role of genes in behavior and cognition; the comparative study of humans and chimps; advanced computing techniques for dealing with highly complex phenomena; the theoretical science of complexity; molecular and quantum computing; gravity; global ecology; and ocean studies. Two general themes emerged. First, the conversation of even the physical scientists was dominated by the astonishing advances in the life sciences following the description of the structure of DNA in 1953 and the elucidation of the genetic code soon thereafter. Second, all agreed that the most interesting new questions are arising at the boundaries between traditional disciplines. Physicists, for example, are studying cosmological questions in their particle accelerators, while astronomers are applying observations made in space to problems defined by traditional physics.

The Carnegie department directors discussed all these ideas and more at their conference at Las Campanas in the fall of 1999. They generally agreed that any new scientific direction should



Fig. 2. James D. Ebert, trustee, former Carnegie president and former director of the Department of Embryology, was affiliated with the institution for 45 years.

Choosing a New Direction

A centennial is a time for study and planning as well as celebration. Our efforts began two years ago when the trustees—successors to the 1902 board—agreed that the strongest affirmative celebration

build on the institution's own knowledge and experience, and that it should also be able to start small and, if warranted, grow to a size no larger than that of a typical Carnegie department and be something distinct from new directions being initiated in other research institutions. The study of higher brain function, for example, is at a stage of great potential for novel advances, but it would not build on any present Carnegie strength. It requires a large undertaking to achieve any scientific impact and is already the focus for major new programs in several leading research universities, all of which seem to be competing for the same group of especially talented investigators. The sense from all these discussions was reported to the trustees, who then examined the options afresh. Finally, global ecology emerged as the most promising and important area to which Carnegie could make a unique and significant contribution.

A Department of Global Ecology

The trustees decided to establish a Department of Global Ecology on the grounds of the Department of Plant Biology on the Stanford University campus on July 1, 2002. Joe Berry and Chris Field, physiological ecologists at Plant Biology who have helped shape this emerging field, will form the nucleus for the new department, which will increase to five members in the next few years, assuming successful fund-raising. Field is serving as the interim director. The department will occupy a small new facility to be constructed next to the present Department of Plant Biology.

Ecology's roots at Carnegie stretch back to the institution's beginnings. As early as 1902, the potential for botanical research included "the function and effect of the forest with regard to atmospheric moisture, precipitation, and runoff, and the converse effect on the forest."¹ Although it was the unique opportunity to study the desert rather than the forest that won initial support,

ecology was part of the program from the earliest days of Carnegie's famous Desert Laboratory outside Tucson, Arizona. As Pat Craig says in the manuscript of her forthcoming centennial book on the history of the Department of Plant Biology, "The pioneering work of the early desert ecologists, the controversial efforts by Clements, the seminal work of Clausen, Keck, and Hiesey, the later broadening of the physiological ecology field by Björkman and his colleagues... stand out as beacons in the department's history."²

But the global ecology planned for the new department would have been beyond the ken of the earlier Carnegie scientists, who had to be content with studying particular plants and species and small, dedicated plots. Now, the development of new satellite sensors, computer models, global informatics resources, and the new approaches for estimating biological diversity afforded by molecular techniques allow large-scale effects to be recorded, analyzed, and modeled (Fig. 3).

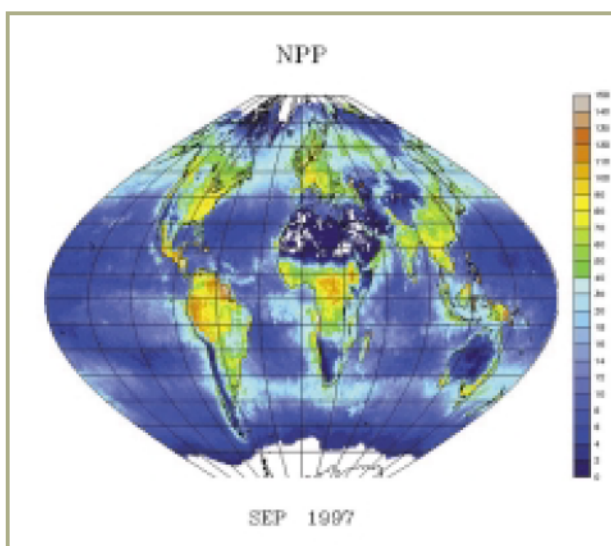


Fig. 3. Data from satellite images have become increasingly important to our understanding of Earth's ecology. This image shows the global net primary production, or NPP, at one point in time. Plants provide food for nearly all life on Earth. They harvest energy from the Sun and convert it into growth, which can then be used by other organisms for food. The amount of growth is known as the NPP. By monitoring this feature over time, scientists can begin to understand the variables that affect its production. (Courtesy NASA/Goddard Space Flight Center.)

¹ Plan for Botanical Research, Carnegie Institution of Washington, Washington, D.C., June 28, 1902.

² Patricia Craig, *Centennial History of Carnegie's Department of Plant Biology* (unpublished manuscript, chap. 14, 2001).

Equally significant and consistent with our advisors' emphasis on multidisciplinary research, the behavior of plants and microorganisms can be integrated with the physical properties of the atmosphere and oceans. Few scientific opportunities are so compelling as we look to the fate of Earth and its life in the coming century. New programs with similar names are beginning to emerge in other institutions. They tend to start from a physical science perspective on atmosphere and oceans. In contrast, Carnegie's new department will take biology as its starting point, recognizing that the complexity of the planet will demand cutting across traditional disciplinary boundaries. And while we did not choose for our new department our advisors' idea of studying advanced computing techniques for dealing with highly complex phenomena, that challenge will surely be on the new department's agenda.

Efforts to assure the health and biodiversity of the planet must be based on scientific understanding or they will waste talent, time, and money. No one pretends that this will be easy or that clear results will come rapidly. For just this reason this unusual plan speaks to new perspectives for a new century while preserving the Carnegie traditions that have proved so compelling in the first 100 years. Over and over, we have seen the scientific success of committed communities of individual scientists, each of whom brings a distinct perspective to a common focus.

Celebrating the Centennial

Of the many ways we will celebrate Carnegie's centennial, those that look to the future have pride of place. The planned Department of Global Ecology is one such element. The other major commitment to the future is a new building to replace the 40-year-old laboratories on the Homewood campus of Johns Hopkins University. It was constructed soon after the late James Ebert became the department's director and now, in spite of its inspiring history, the building is inadequate for modern research and instrumentation. Johns

Hopkins University has given us a fine, wooded site for the new building and has joined in our planning in a collegial spirit (Fig. 4).

The All-Carnegie Symposium planned for May 3 and 4, 2002, also looks to the future. Reflecting the global ecology initiative, it will emphasize the seamless connections between the physical and biological aspects of Earth. At one end of the continuum, the Observatories' Andrew McWilliam's work on the formation of the elements in stars speaks to the origin of the materials used to build the Earth and its life. At the other end are Allan Spradling's experiments on how animals assure the continuity of life through the formation of germ cells, eggs, and sperm. These talks will be tied together as we hear, among other things, about how the Earth's physical environment provides the chemical and solar energy for life and how that solar energy influences our daily existence. One reason for scheduling the symposium in May is so that all Carnegie scientists have an opportunity to visit the centennial exhibition, *Our Expanding Universe*, which will be on display at the administration building from December 7, 2001, through May 31, 2002.



Fig. 4. This is a model of the new Department of Embryology building (left) to be built on the Johns Hopkins University campus in Baltimore, Maryland. (Courtesy Zimmer Gunsul Frasca Partnership.)



The centennial exhibition looks back at the research accomplishment of Carnegie scientists beginning soon after the institution was founded. Some of the stories are familiar, iconic ones, while others—fascinating but previously obscure—emerged from the historical materials stored in the institution's and other archives. The science will be the main subject, but the exhibits will also document some of the critical decisions made by generations of trustees and presidents. These actions influenced profoundly not only the early research but also the practices we use today. Many marvelous old photographs and documents will be displayed, along with instruments used in the past. The exhibition itself builds on a tradition, though one long abandoned. Up until World War II, department members annually brought exhibits about their work for display in the administration building, which was opened to the public. Some of the themes and illustrations in the exhibition will also appear in the centennial history book written by James Trefil and Margaret Hazen, with an introduction by Timothy Ferris. Five additional books that provide more detailed scientific histories of the five current departments are also in preparation.

Celebratory symposia are planned at these several departments. These will highlight current research as well as point to the future. For Carnegie astronomers in Pasadena and planetary scientists at the Department of Terrestrial Magnetism, much of that future research will exploit the Magellan telescopes. The images from the Walter Baade telescope, in scientific operations since February 2001, have surpassed expectations. The Landon Clay telescope, which should be fully operational by the time this Year Book appears, should be better still.

Two scientific symposia, one on the physics and chemistry of rock-forming materials and the processes that shaped the Earth and terrestrial planets and one on prebiotic chemistry and biological processes on the primitive Earth, are being planned at the Geophysical Laboratory. The astrobiology program at DTM and GL is an important example of the multidisciplinary research that will define the future, depending as

it does on connecting chemical, physical, and biological insights and experiments. Unburdened by strict departmental divisions by discipline, Carnegie scientists can be flexible in their choice of questions and strategies.

Special programs are also being prepared for the broad public. The two departments at Broad Branch Road in Washington, GL and DTM, will tell their neighbors about the institution and their current research at a series of talks. Both the Observatories and Plant Biology in California are also planning public lectures. At the administration building in Washington, there will be an enhanced program for the Capital Science lectures series.

Affirming the Individual

Our attention to Carnegie history during the past year has confirmed a consistent, institutional confidence in individual investigator tempered by an understanding that scientific success, especially in multidisciplinary endeavors, may require individuals scientists to join occasionally in group efforts. It seems especially important to reaffirm this tradition at this time because during the past year distinguished biologists have stated publicly and to some fanfare that now, after the determination of the human genome DNA sequence, all future significant biological research will be accomplished by large teams using massive databases, what is sometimes called biology *in silico*. Such sweeping statements are not new. Similar ones were made, for example, soon after the end of World War II. Vannevar Bush (Fig. 5), who was surely proud of the successful scientific teams he organized during the war, nevertheless reminded us that "it was Andrew Carnegie's conviction that an institution which sought out the unusual scientist, and rendered it possible for him to create to the utmost, would be worth while [sic]. More than forty years of experience has justified this conviction."³ The same can now

³ Vannevar Bush, Report of the President, 1950. *Carnegie Year Book* 49/50, Washington, D.C., 2001.

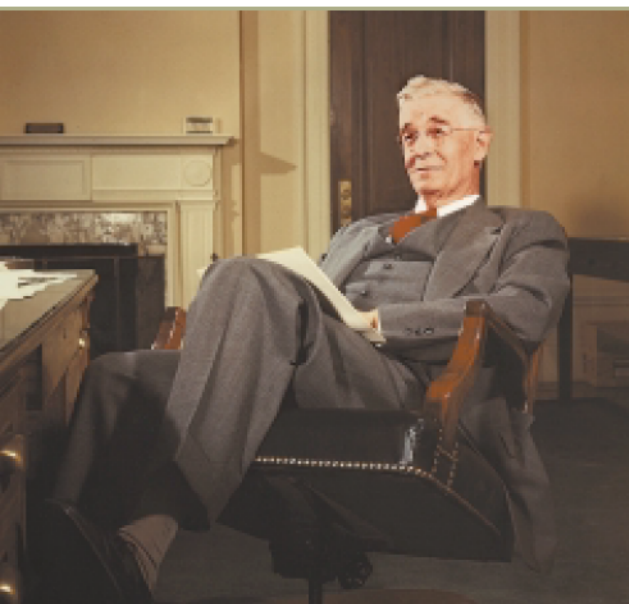


Fig. 5. Vannevar Bush, Carnegie president from 1939 to 1955, is shown in his P Street office in Washington, D.C.

be said of a century of experience. It remains true that the individual alone can judge whether a joint or a personal effort will be more creative or productive in each instance.

In the 50 years that followed Bush's remarks, Carnegie scientists often reinforced his position. Speaking to 500 scientists gathered at the Rockefeller Institute in 1959, the sagacious Merle Tuve, then director of DTM, said, "Huge new synchrotrons and cosmotrons and electronic computers, and polar expeditions and balloon and rocket flights and great government laboratories costing more each year than the total academic costs of many of our greatest universities—all of these conspicuous aspects of our new national devotion to science are subsidiary and peripheral. They do not serve appreciably to produce or develop creative thinkers and productive investigators." In case his listeners had missed the point, Tuve added that "no array of feedback arguments will convince very many of us that the real germ of new knowledge is the product of team activity" (Fig. 6). As recently as the last Carnegie Year Book, Chris Somerville, describing the large

project designed to determine the function of all higher plant genes by 2010, wrote, "It is axiomatic that scientific discoveries cannot be planned but arise unexpectedly from individuals following the imperatives of personal curiosity." He added, "In fact, it is technical accomplishments that can be planned, rather than discovery per se." But Somerville was no more dogmatic than Tuve, whose team had produced the proximity fuse. He continued, "While many discoveries seem to obey this rule, it is also true that great progress has been made in many fields by providing support for scientists working toward specific, large goals."

We should keep this complex interplay between the individual and the group in mind as we contemplate the many ways that scientists can respond to the world crisis engendered by the hideous attacks on the United States on September 11, 2001, and the ensuing biological menace. Carnegie scientists have a relevant tradition that is as strong as our dedication to the independence of our scientists. During World War I and especially in World War II, many of our predecessors set aside their own research and applied their talents and knowledge to unique solutions to the nation's many challenges. That work often depended on an individual with smart ideas and technical expertise and a group that could bring the idea to productive reality. It is impossible now to predict how the threats to our country and the world will develop between the writing and the reading of these words no less than in the coming years. We can, however, be certain that scientific knowledge and methods will be needed and that Carnegie scientists will strive, once again, to apply themselves to the challenges.

—Maxine F. Singer
November 2001

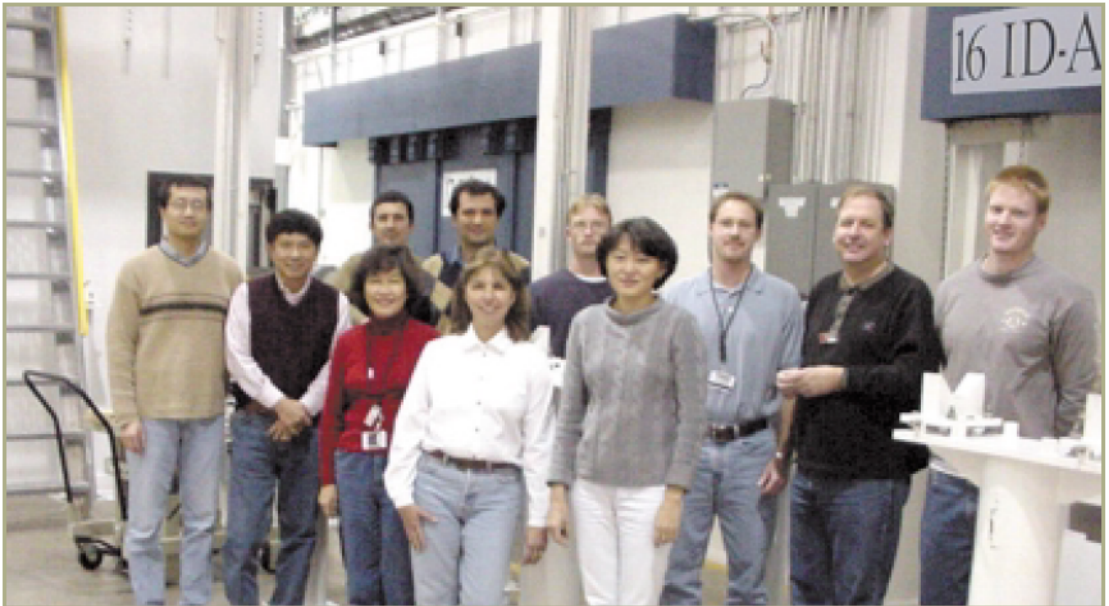


Fig. 6. Scientists at Carnegie engage in many collaborative efforts. Members of the Geophysical Lab's High Pressure Collaborative Access Team (HP CAT) at Argonne National Lab, for instance, are constructing a beamline facility to study a range of high-pressure phenomena. Team members (back row from left) include Michael Hu, David Mao, Daniel Häusermann, Daniel Errandonea, Sean Turbett, Clayton Pullins, Richard Benn, and Eric Rod. In the front row from left are Agnes Mao, Veronica O'Connor, and Yue Meng.

LOSSES

James D. Ebert, 79, trustee, former president of the Carnegie Institution and former director of the Department of Embryology, and his wife, **Alma**, 78, died in an automobile accident near Baltimore on May 22, 2001. Ebert was affiliated with Carnegie for 45 years. During World War II, lieutenant Ebert served in the U.S. Navy; he was decorated with the Purple Heart. He received his Ph.D. in experimental embryology from the Johns Hopkins University in 1950 and then served on the faculties of the Massachusetts Institute of Technology and Indiana University. He directed the Department of Embryology from 1956 until 1976. For several of those years he concurrently served as president and director of the Marine Biological Laboratory at Woods Hole, Massachusetts. During his tenure at Embryology, Ebert forged a closer relationship between Hopkins and Carnegie, and he was instrumental in bolstering a new research focus on developmental mechanisms at the cellular and molecular levels. He became president of Carnegie in 1978, a position he held until 1987.



James and Alma Ebert

William R. Hewlett, Carnegie trustee emeritus and cofounder of the company Hewlett-Packard, died January 21, 2001, at the age of 87. A trustee since 1971, Hewlett served as chairman of the board from 1980 until 1986 and became a trustee emeritus in 1990. Hewlett graduated with a B.A. from Stanford University in 1934 and obtained his master's degree in electrical engineering from MIT in 1936. While president of Hewlett-Packard he developed the "HP Way," the company's belief in promoting individual creativity, a relaxed management hierarchy, and trust in employees. He served on the boards of the Stanford Medical Center, the Institute of Electrical and Electronics Engineers, and the Kaiser Foundation Hospital, among others. In 1985 Hewlett received the highest scientific honor in the U.S., the National Medal of Science.



William R. Hewlett

RETIRING

George Wetherill, director of the Department of Terrestrial Magnetism from 1975 to 1991, has retired. A Staff Member from 1953 to 1960, and again after his directorship until 2001, Wetherill received America's highest scientific honor, the National Medal of Science, in 1997. In the 1950s, Wetherill was among a group of Carnegie scientists who developed geochemical methods involving natural radioactive decay to date the Earth's rocks. In the 1970s, he began theoretical explorations into the origins of meteorites and the terrestrial planets, developing a technique to calculate the orbital evolution and accumulation of planetesimal swarms. Prior to the discovery of extrasolar planets, he calculated models of terrestrial planet systems orbiting other stars.



George Wetherill receiving the National Medal of Science in 1997.

GAINS

Stephen P. A. Fodor became a member of the board of trustees in December 2000. Dr. Fodor is currently the chairman and chief executive officer of Affymetrix, of Santa Clara, California. In 1993 he co-founded the company, which produces high-density oligonucleotide arrays and supporting equipment for gene analysis. He is a member of the American Chemical Society, the Biophysical Society, and the AAAS.



Stephen Fodor

Deborah Rose is a new member of the board of trustees as of May 2001. Dr. Rose received her Ph.D. from Yale's Department of Epidemiology and Public Health. She works for the National Center for Health Statistics of the Centers for Disease Control. She is a member of Harvard's School of Public Health Alumni Council, the American Public Health Association, and the Society for Epidemiologic Research.



Deborah Rose

In July 2001 the Department of Terrestrial Magnetism welcomed Staff Member **Alycia Weinberger**, an astronomer who studies the conditions for planet formation by detecting and analyzing the circumstellar disks in which planets are born. Weinberger comes from UCLA, where she was a NICMOS and astrobiology postdoctoral research astronomer. She received her Ph.D. from the California Institute of Technology.

Cosmochemist **Larry Nittler** joined the DTM research staff in March 2001. Nittler investigates primitive extraterrestrial materials, including presolar grains and interplanetary dust particles, and their link to the evolution of stars and the solar system. He comes to DTM from NASA Goddard, where he served on the X-ray/Gamma-Ray Spectrometer (XGRS) team of the Near Earth Asteroid Rendezvous mission. Nittler received his Ph.D. in physics from Washington University.

Andrew Steele accepted a position as Staff Member at the Geophysical Lab (GL) in February 2001. He uses high-magnification microscopy and surface-sensitive analysis to study a variety of terrestrial and extraterrestrial samples to establish biosignatures, which indicate the presence of life. Previously Steele served as a consultant at NASA's Johnson Space Center and was also an assistant research professor in the Department of Microbiology at Montana State University. He received his Ph.D. from the University of Portsmouth.

Zhi-Yong Wang, Plant Biology's newest Staff Member as of June 2001, studies a plant steroid hormone called brassinosteroid, which is important to growth and development, particularly in respect to the way light is used for growth. He comes from the Salk Institute and the Howard Hughes Medical Institute in San Diego. He received his Ph.D. in molecular, cell, and developmental biology from UCLA.

TRANSITIONS

William Coleman is now a senior trustee.

Inés Cifuentes has been appointed director of the Carnegie Academy for Science Education (CASE) and First Light.

Vera Rubin has been appointed a Senior Fellow at the Department of Terrestrial Magnetism.

HONORS

Trustee **Sandra Faber**, professor of astronomy and astrophysics at UC-Santa Cruz, was selected to the American Philosophical Society.

Trustee **Charles H. Townes** has received the National Academy of Engineering's 2000 Founders Award. The award recognizes Townes' lifelong contributions to engineering.

Plant Biology Director **Chris Somerville** was one of eight colleagues awarded the Kumho Award by the International Society for Plant Molecular Biology. The award, sponsored annually by the Kumho Cultural Foundation of Korea, has a prize of \$36,000. The year 2000 award recognized the contribution of the *Arabidopsis* Genome Initiative group in completing the *Arabidopsis* sequence.

Observatories' **Allan Sandage** was selected a Foreign Member of the Royal Society (London).

Plant Biology's **Chris Field** and GL's **Russell Hemley** were elected to the membership of the National Academy of Sciences at the academy's 138th annual meeting.

Paul Butler (DTM) and Geoffrey Marcy (UC-Berkeley) were awarded the Henry Draper Medal at the National Academy of Science's 138th meeting. The award recognizes their "pioneering investigations of planets orbiting other stars via high-precision radial velocities."

Larry Nittler (DTM) received the Nier Prize from the Meteoritical Society. The Nier Prize is awarded "for a significant contribution in the field of meteoritics and closely allied fields of research."

GL Staff Member **Douglas Rumble** has been appointed Geochemistry Fellow of the Geochemical Society and the European Association for Geochemistry.

Winslow Briggs (Plant Biology) received the Finsen Medal, which has been awarded every four years since 1937 by the Association Internationale de Photobiologie for outstanding research in photobiology, at the International Photobiology Congress in San Francisco.

Arthur Grossman (Plant Biology) received a Lady Davis Fellowship as a visiting professor at Hebrew University in Israel.

Embryology Staff Associate **Jim Wilhelm** has been awarded a Life Sciences Research Foundation Fellowship.



CASE/FirstLight's **Greg Taylor** was accepted into the Intel Master Teacher Program. Upon completion of the program, Greg will receive a \$5,000 cash grant for FirstLight to purchase computer equipment.

Lora Armstrong, a GL intern who worked with Bjørn Mynsen last year, won the first place for best Earth science project from AGI; second prize for women in geoscience; and third place in the Earth and space science category at the International Intel Science Fair in May.

Toward Tomorrow's Discoveries

The Carnegie Institution received gifts and grants from the following corporations, foundations, individuals, and government agencies during the period July 1, 2000, to June 30, 2001.

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More Than \$1 Million

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THE DIRECTOR'S REPORT

"I WOULD SAY: LET THEM REMEMBER THAT THERE IS A MEANING BEYOND ABSURDITY. LET THEM BE SURE THAT EVERY LITTLE DEED COUNTS, THAT EVERY WORD HAS POWER, AND THAT WE CAN—EVERYONE—DO OUR SHARE TO REDEEM THE WORLD IN SPITE OF ALL ABSURDITIES AND ALL FRUSTRATIONS AND ALL DISAPPOINTMENTS. AND, ABOVE ALL, REMEMBER THAT THE MEANING OF LIFE IS TO BUILD A LIFE AS IF IT WERE A WORK OF ART."

ABRAHAM JOSHUA HERSCHEL'S MESSAGE TO YOUNG PEOPLE

The events of September 11, 2001, marked all of us. As a consequence, I am certain today that the work of the Carnegie Academy for Science Education (CASE) in the public schools of the nation's capital matters more than ever.

The CASE staff has been visiting schools in Washington, D.C., since 1994 to improve the quality of the city's elementary science education. We have met amazing teachers and principals along the way who have inspired us by their commitment to the education of their students. And they have told us what CASE has done for them: it has energized their performance, changed their way of teaching science and mathematics, and made them think about who among their students can achieve more and who cannot. Although educational improvements are sorely needed, CASE has provided the only long-term professional development program in science and mathematics education in the city. Our work is paying off. We are respected for the quality of our teacher development, our high standards, and our professionalism. These are rare qualities in a school system that has steadily deteriorated since

the early 1970s. As one of the teachers at Shepherd Elementary School said, "If it's Carnegie, it's quality."

The CASE staff continues its work in the city's schools because of the children. The children, most of whom are African American and Latino, have been forgotten by the U.S. Congress, which controls the city's affairs, and by those in city government. Arlene Ackerman, superintendent of D.C. Public Schools from 1998 to 2000, introduced the Stanford 9 Achievement Tests in language arts and mathematics for students in grades 1 through 12 as a way to measure the success of the existing system. The low achievement of the majority of the students—80% of 10th grade students scored below the basic level in mathematics—was a shock to the superintendent and the public. The CASE staff, among others, had already realized the extent of the problem, and was aware of the "delusion of adequacy" shared by many in the education community. The Stanford 9 results tore away that veil.



Fig. 1. The Carnegie Academy for Science Education (CASE) and the First Light Saturday science school teach elementary science with hands-on experiments. Here students learn how to construct wind racers using the Linx Design Technology System. The project teaches them how to devise a vehicle that can harness the forces of nature for maximum performance. (Courtesy Greg Taylor.)



As a result of the CASE track record, the National Science Foundation in September 2000 approved a grant to fund a partnership called DC ACTS. It is a group effort between the D.C. Public Schools (DCPS), the Carnegie Institution of Washington, and the American Association for the Advancement of Science (AAAS) to launch a pilot program to improve science and mathematics education in the city. DC ACTS was the creation of three women: Arlene Ackerman, DCPS superintendent; Maxine Singer, Carnegie president; and Shirley Malcom, director of education and human resources at AAAS. CASE is responsible for the program in 15 elementary schools, whose students vary in family income, cultural background, and level of achievement. AAAS is responsible for results at the two high schools chosen for the program, Wilson and Ballou, and the four middle/junior high schools.

We at CASE have been hard at work with DC ACTS. Thus far we have written the science standards for the D.C. Public Schools; we continue to

teach science, mathematics, and technology courses during the summer and the school year; we are writing instructional plans for teachers on how to teach elementary school science in connection with the mathematics textbook; and we are providing our elementary schools with science materials and classroom support. We also recently hired Dr. Toby Horn as the DC ACTS/CASE staff person to coordinate all of the science, mathematics, and technology programs in the DCPS system. She works with the chief academic officer, and her office is at DCPS administrative headquarters, which helps forge a close relationship with the schools.

For the first time since we began working in the D.C. Public Schools we are optimistic that the serious job needed to make instruction the focus of the school system has truly begun. The current school board is composed of intelligent and dedicated people. Dr. Paul Vance, the superintendent, came out of retirement after years in the Montgomery County Public Schools to lead D.C.

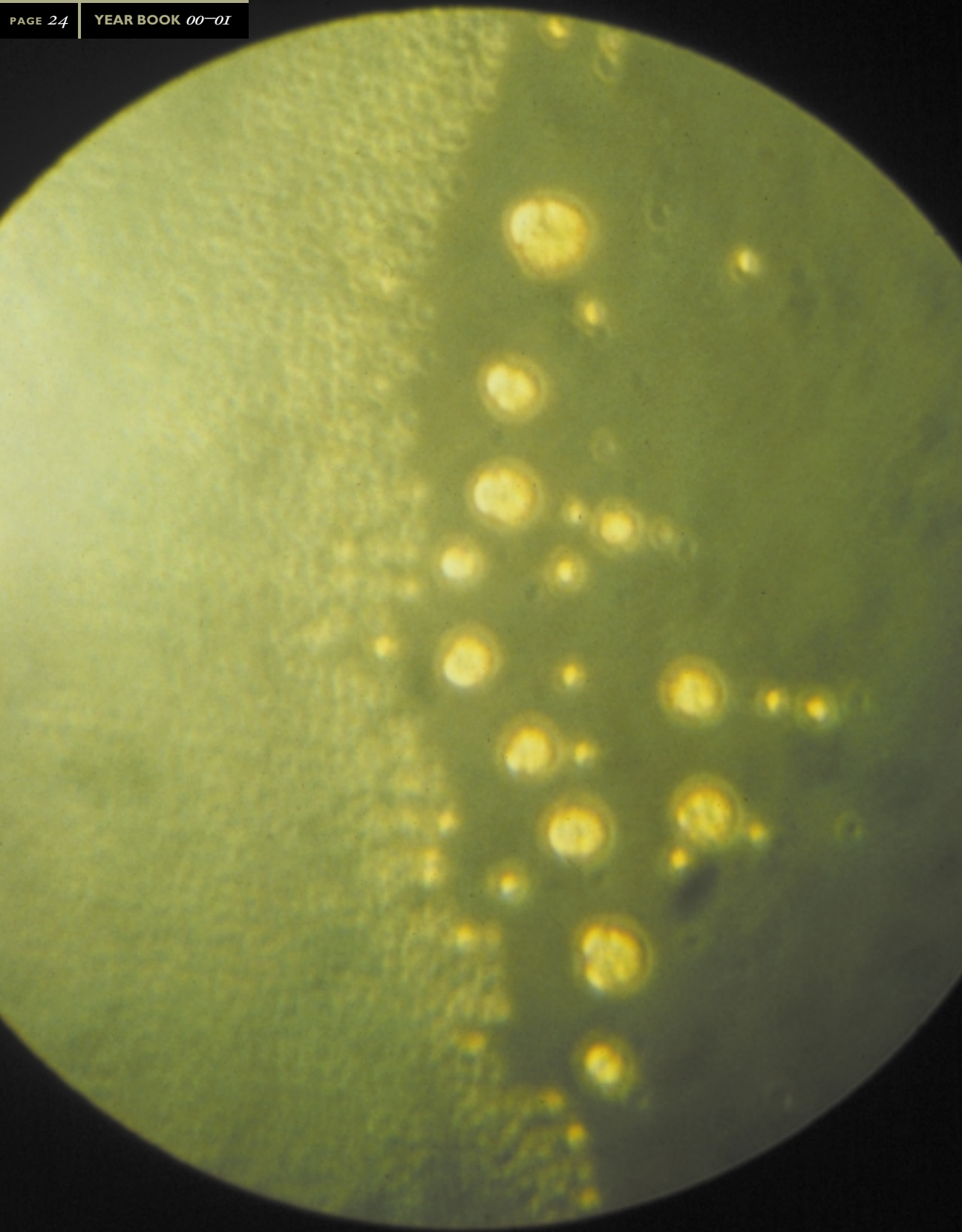
He knows what a working school system looks like and is committed to providing a quality education to the children of the nation's capital. We all know that our efforts will be in vain, however, without the support of the mayor and the Congress. We hope that they will recognize the strides we are making and join us in educating the city's children.

—*Inés Lucía Cifuentes*



Fig. 2. First Light children learn how materials absorb liquid by examining a disposable diaper.





THE DIRECTOR'S REPORT

The Geophysical Laboratory (GL) has remained at the forefront of research into the fundamental physics and chemistry of the Earth and other planets. The lab has seen some remarkable results over the past year—from the creation of new materials to identifying a possible mechanism for transforming chemistry into biology on the young Earth. The following pages highlight some of these results.

The Earth's Core: Understanding Iron at High Pressure

Elasticity of iron

The iron in Earth's inner core is important to the dynamics of the outer core, the behavior of the magnetic field, and the thermal state of the planet. The inner core is anisotropic—that is, seismic waves travel faster along the rotation axis than in the direction of the equator. To understand this anisotropy, elastic constants governing sound speeds need to be determined. Although direct measurements at core pressures (up to 340 GPa, or about 3.4 million atmospheres) and temperatures (about 6000 K) are not yet feasible, these constants can be estimated by using first-principles theory.

Ronald Cohen of GL, in collaboration with Gerd Steinle-Neumann and Lars Stixrude at the University of Michigan, has computed the separate elastic constants along the principal crystal axes of the hexagonal close-packed (hcp) structure of iron, which exists at high pressures. They found a large thermal dependence for the elastic constants so that the sense of anisotropy—the direction with the fastest sound speeds—is reversed at higher temperature. The researchers also found that the magnitude of anisotropy is much larger than previously thought. A 30% alignment of iron

grains along the Earth's rotation axis is sufficient to give this seismologically observed effect. These data and observed seismology allow us to constrain the inner-core temperature to about 6000 K.

Magnetism in iron

A number of experimental studies have shown hcp iron to be nonmagnetic, or at least to have no magnetic order. Ron Cohen, however, has found a stable antiferromagnetic structure of hcp iron that is theoretically more stable than the nonmagnetic solution. Via calculations, he recently discovered an even more stable noncollinear magnetic structure, which is an important result for geophysics and for understanding the newly discovered superconductivity in hcp iron. It remains unknown, however, why this magnetic structure has not been detected experimentally. To understand this, further work is under way comparing Ron's calculations with experiments conducted by the high-pressure group at GL (Fig. 1).

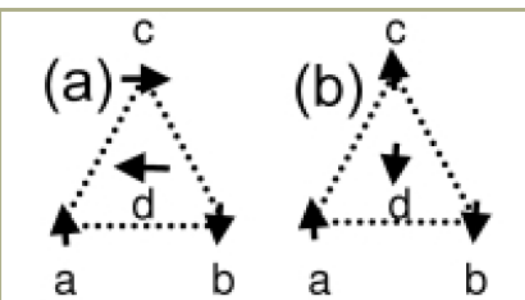


Fig. 1. This is the most stable magnetic structure found for the ground state of hcp-Fe (a). It consists of atoms with magnetic moments that point in opposite directions (antiferromagnetic moments) in different layers. The moment in each layer is rotated by 90 degrees from the previous one, giving a noncollinear structure. (b) The most stable collinear structure is shown here. Collinear magnetism is frustrated in the hcp structure because it is impossible to make all of the moments antiferromagnetic with respect to one another.

Left: Life may have begun as a geochemical process. At high temperatures and pressures, small organic molecules, such as carbon dioxide and water, combine to form larger molecules. Some of them assemble spontaneously into vesicles similar to those in cells. Such a vesicle, as shown here, may have been among the first steps in the evolution of life. (Courtesy Robert Hazen and David Deamer.)

Seismic velocities in iron

Ultra-high pressures change the properties of materials. An important example is the pressure dependence of the vibrational dynamics of iron. Thermodynamic and elastic parameters — essential for interpreting seismological observations — are directly related to a quantum unit of molecular vibration in the solid state called a phonon. Previous high-pressure measurements of ultrasonic phonon velocities, shock-wave velocities, stress-strain relations, and zone-center E_{2g} Raman phonon have only provided partial phonon information. Our knowledge of the full-phonon spectrum of hcp iron at core pressures is currently based on theoretical calculations.

Ho-kwang (Dave) Mao has been collaborating with several groups at the Advanced Photon Source at Argonne National Laboratory and a group at University College London to develop a new method for determining the phonon density of states of iron to 153 GPa, a pressure beyond Earth's core-mantle boundary. Key parameters controlling the physical states of iron-rich planetary cores have been estimated previously by shock-wave measurements and theoretical calculations. Mao's static high-pressure data at 300 K, and shock-wave curves at 8000 to 9000 K, indicate that these seismic velocities of pure iron under solid inner-core conditions are slightly higher than the seismic PREM model. Additional light-element alloys in the inner core would further increase this difference, but the addition of a heavy-element alloy, such as 5% to 10% nickel as suggested by geochemical evidence, would be in perfect agreement with the seismic model.

The Earth's Mantle: Between Core and Crust

Studies of the role of water in lubricating the motion of mantle material

Bjørn Mysen has been examining the solubility of water in magmatic liquid to understand igneous and hydrothermal processes in planetary interiors.

The amount of water present in these hot fluids as a function of pressure and temperature has a large effect on their dynamic behavior. For instance, the ascent rates of magmatic fluids depend on the properties of H_2O in the melt and on the mechanisms of volcanic eruption near planetary surfaces.

Accurate information on the solubility and solution mechanisms of H_2O in fluids and melts requires a quantitative description. Mysen has conducted a series of experiments to obtain this information in model hydrous silicate melt systems containing the oxides of sodium, aluminum, and calcium.

The greater buoyancy of hydrous melts is the driving force behind the more rapid ascent of hydrous magmas over anhydrous ones. Once these melts reach their level of neutral buoyancy in the crust, crystallization begins. The melt then reaches their water-saturation level and steam is formed. From Mysen's work, it appears that steam formation in the chambers beneath many volcanoes constitutes between 5% and 25% of the total energy that can contribute to volcanism.

Life: Looking for its Origins

Searching for ancient biochemical processes

Recent theories propose that life arose in primitive hydrothermal environments where chemical reactions analogous to the reductive citrate cycle (RCC) occur. The RCC is a primary biological pathway for carbon fixation. A primitive geochemical equivalent to the RCC is presumed to have developed as a natural consequence of the geochemistry of the young, prebiotic Earth. George Cody, with Jay Brandes, Robert Hazen, and Hatten Yoder at GL, has demonstrated that a prebiotic pathway might result from a natural set of geochemical reactions and form a cycle similar to the RCC. These scientists have attempted to reverse-engineer the primitive cycle by observing the pathways by which citric acid is decomposed. Three principal decomposition pathways of citric acid were observed under hydrothermal condi-

tions. The pathway to propene and carbon dioxide (CO_2) was selected as one that might have the most promise for generating a primitive RCC-type cycle. This hypothesis was tested in separate experiments in which natural transition metal sulfides were used to catalyze the reverse reactions under natural hydrothermal conditions.

The goal of the research was to convert an olefin such as propene to a monocarboxylic acid by adding CO_2 , then convert the monocarboxylic acid to a dicarboxylic acid by the same method, and ultimately produce a tricarboxylic acid like citric acid. Cody and co-workers used nickel sulfide (NiS) as the catalyst in the presence of carbon monoxide (CO). An olefin, 1-nonene, was converted to the monocarboxylic methacrylic acid at elevated temperature and pressure in the presence of NiS and CO . Methacrylic acid was then converted to the dicarboxylic methylsuccinic acid in the same way, and the dicarboxylic itaconic acid

was converted into the tricarboxylic hydroaconitic acid. These results point to a plausible pathway for citric-acid synthesis that may have provided a geochemical ignition point for the reductive citrate cycle (Fig. 2).

Left- and right-handed biochemistry

Life's chemistry is distinguished by its use of handed or "chiral" molecules—so-called left-handed (L) amino acids and right-handed (D) sugars. Virtually all nonbiological processes, however, make no distinction between L and D variants. For years scientists have searched for a natural process that might discriminate between left- and right-handed molecules—a critical step in the transition from prebiological to biological chemistry.

This step, called chiral selectivity, is crucial to forming chainlike molecules of pure L-amino

Hydrothermal Experiments Point to a Primitive Carbon Fixation Pathway Cody et al. (In Press) *Geochim. Cosmochim. Acta*

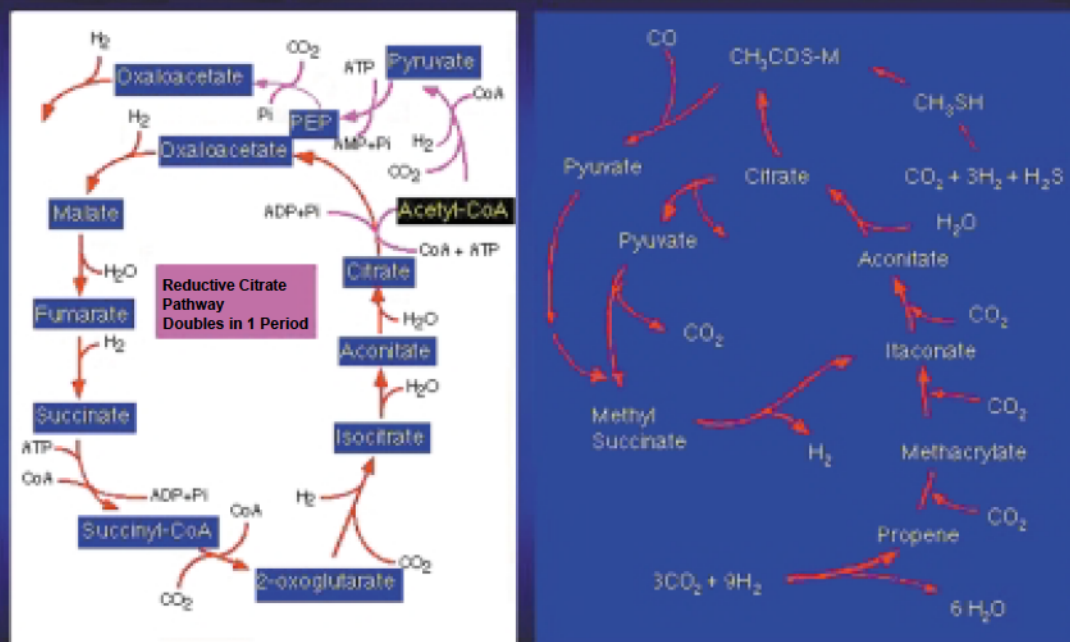


Fig. 2. The carbon fixation pathway of the reductive citrate cycle is shown at left. At right is a plausible prebiotic carbon fixation pathway derived from experimental simulations of hydrothermal organic reactions in the presence of catalytic transition metal sulfides.

acids (including proteins) and D-sugars (as found in DNA and RNA) and thus represents the link between prebiotic synthesis of simple molecules and the assembly of much larger self-replicating molecules.

Carnegie scientists Robert Hazen and Timothy Filley (Filley is now at Purdue University) and Glenn Goodfriend (George Washington University) have achieved D- and L-amino acid excesses greater than 10% by exposing crystals of the common mineral calcite—which forms limestone and the hard parts of many sea animals—to a dilute solution of aspartic acid. The D- and L-aspartic acid molecules are preferentially adsorbed onto different crystal faces of the mineral.

Calcite crystals are as common today as they were during the Archean Era about 4 billion years ago, when life arose. These experiments demonstrate a plausible process by which the mixed D- and L-amino acids in a dilute “primordial soup” could be concentrated and selected on a readily available mineral surface (Fig. 3).

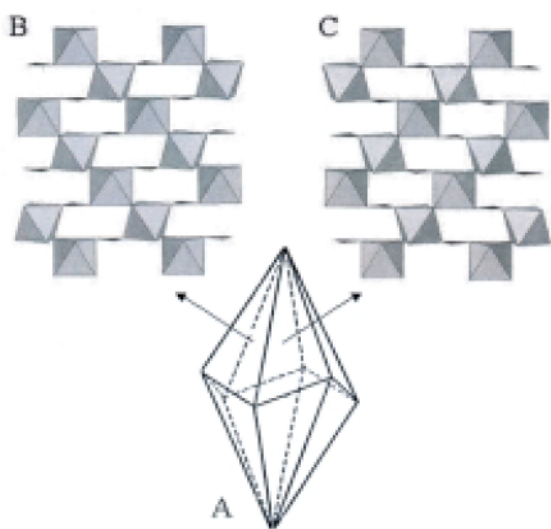


Fig. 3. The common mineral calcite (calcium carbonate) exhibits adjacent crystal faces with mirror symmetry. Left- and right-handed amino acids selectively adsorb onto these faces—a process that might have contributed to the prebiotic concentration and selection of these important biomolecules.

A new technique to investigate fossil isotopes

Postdoctoral fellows Guixing Hu and Peiling Wang and Staff Member Douglas Rumble are studying sulfur isotope geochemistry in a variety of terrestrial and meteoritic samples. Hu and Rumble built and validated a new laser microprobe to measure sulfur isotopes in minute amounts of sulfide, and are using it to examine the large fractionation of $^{34}\text{S}/^{32}\text{S}$ caused by microbes dependent on the reduction of oxidized sulfur to sulfide for their metabolic energy. Such large fractionations are among the most durable known markers of ancient organisms and have been recognized in Precambrian rocks. The fractionation of all four sulfur isotopes by microbes is being investigated in collaboration with microbiologists James Scott, David Emerson, Ken Nealson, and former postdoctoral fellow Pan Conrad. Former Geophysical Lab postdoctoral fellow James Farquhar and colleagues at the University of California, San Diego, reported distinctive $^{33}\text{S}/^{32}\text{S}$, $^{34}\text{S}/^{32}\text{S}$, and $^{36}\text{S}/^{32}\text{S}$ fractionations in Archean rocks older than 2.5 billion years. Their discovery substantiates the hypothesis that Earth's earliest atmosphere was less oxygenated than at present (Fig. 4).

Meteorites

Extraterrestrial organic matter in meteorites

The organic material in primitive chondritic meteorites retains a record of organic synthesis in the interstellar medium (ISM) and possibly in the solar nebula; it may also have been an important component of the prebiotic organic material on the early Earth. The vast majority (~90%) of extraterrestrial carbon is bound in a dark, insoluble macromolecular phase. Although substantial progress has been made in characterizing the soluble organic molecules extracted from carbonaceous meteorites, there remains an incomplete and sometimes contradictory description of the molecular structure of the predominant insoluble organic carbon. Consequently, there is no well-constrained

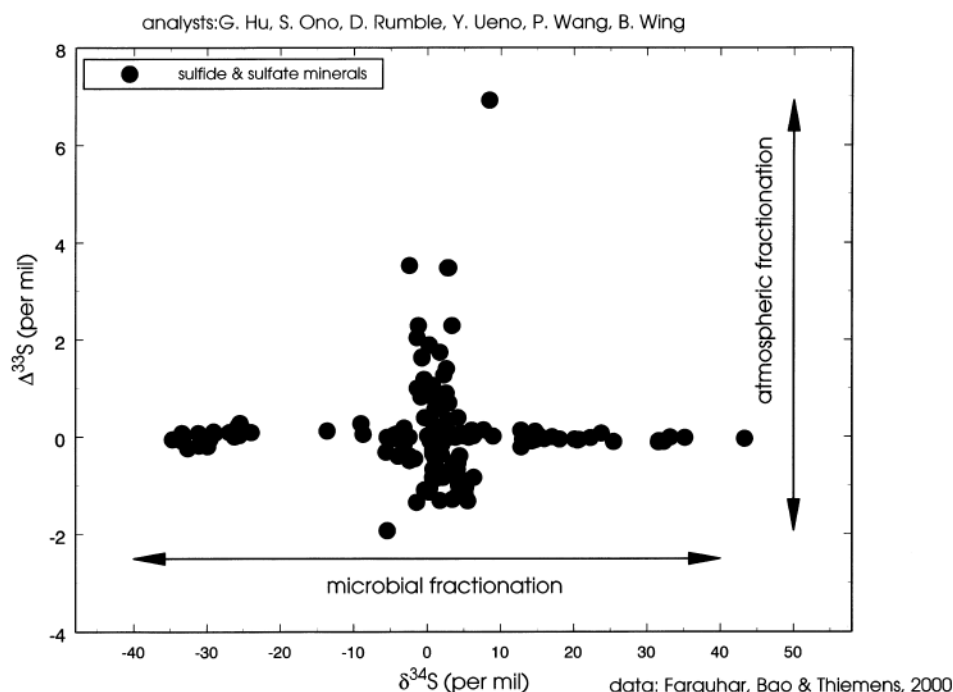


Fig. 4. Sulfur isotope analyses serve a dual purpose in that they provide evidence of the former existence of microbes and a record of ancient atmospheric photochemistry.

theory to explain how molecules evolved from deep within dense molecular clouds to form the complex organic matter within carbonaceous chondritic meteorites that have bombarded the Earth for the past 4.5 billion years.

George Cody, with Conel Alexander and Fouad Tera of DTM, has recently applied solid-state nuclear magnetic resonance (NMR) spectroscopy to analyze the organic macromolecular substance isolated from the Murchison meteorite. The group found an extremely complex structure with a spectacular array of oxygen and organic functional groups. Contrary to previous analysis, no evidence was found for large graphitelike structures. The average sizes of the molecular clusters in the macromolecular material are relatively small. These results provide the foundation to study chemical evolution from the interstellar medium to the early solar nebula (Fig. 5).

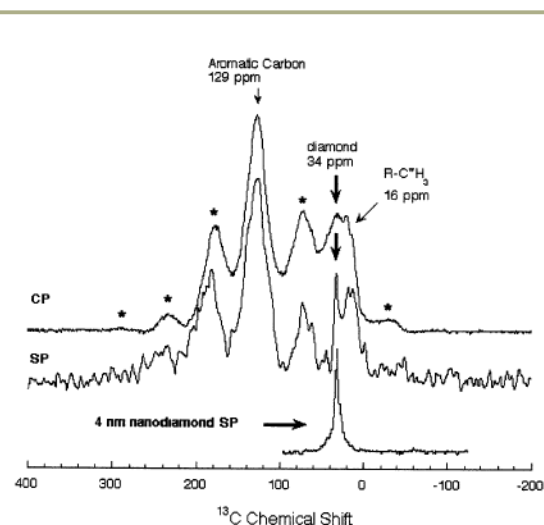


Fig. 5. This is a solid-state ^{13}C NMR spectra of the Murchison meteorite. The sharp peak at ~34 ppm corresponds to the presence of interstellar diamonds that were expelled in the circumstellar envelopes of collapsing stars and incorporated later into the source region of the nebula from which our solar system formed.

Fundamental Properties of Materials

Transforming molecules into new materials under high pressure

During the past year, Rus Hemley made new discoveries in simple molecular materials at very high pressure. In one area, a new nonmolecular form of nitrogen was recovered at ambient conditions and low pressures when decompressed from 200 GPa (2 million atmospheres) where it was formed. This result suggests that it could be used as an energetic material. When warmed to above ~50 K, the new form of nitrogen back-transformed to its normal diatomic state (N_2). This behavior shows loose parallels to phosphorus, which sits below it in the periodic table.

Studies of triatomic systems provide intriguing comparisons with the behavior of N_2 . Several years ago, it was reported that CO_2 transforms at 40 GPa and ~2000 K to an extended-framework solid, with a structure analogous to common SiO_2 minerals. Recent studies of this system at GL revealed additional transitions in CO_2 at high-pressure and high-temperature (P-T) conditions, including the breakdown to the elements diamond and oxygen at temperatures >2000 K, which corresponds to conditions in planetary interiors.

Recent studies of boron showed additional phenomena. Hemley and co-workers measured the conductivity of boron as a function of pressure and temperature to above 200 GPa. On compression, the resistance was observed to drop, but the temperature dependence showed that the material is an insulator over a wide P-T range. At 175 GPa, however, the material exhibited metallic behavior. Cooling it to a low temperature showed that it is also a superconductor, with a critical temperature (T_c) of ~6 K. With increasing pressures, T_c increased at a remarkably high rate, reaching 11.5 K at 250 GPa. This is the highest pressure measurement of both conductivity and superconductivity yet reported.

Theory and practice!

A key element of our national security is for the navy to be able to "see" underwater. This is done with sonar and hydrophones that generate and sense sound. These devices use transducers—typically piezoelectrics—that interconvert mechanical and electrical energy. Ultrasound is also important in medicine and in the diagnosis of the structure of materials. The materials that are mostly used as piezoelectrics today are PZT ($(Pb(Zr,Ti)O_3)$ ceramics. Recently, new materials have been discovered that have much greater coupling strength. Ron Cohen has developed a model for understanding how all of the large strain piezoelectrics work. He found that the large strain arises from rotation of the polarization in an applied electric field, or in response to strain (Fig. 6).

New Facilities

A new instrument to investigate fossil biomolecules

A new instrument for detecting trace amounts of high-molecular-weight organic compounds was

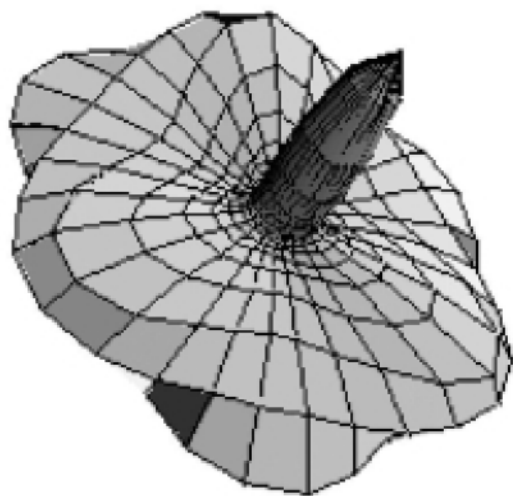


Fig. 6. Young's modulus for PZT versus direction is shown here. It is very soft in all directions that allow for polarization rotation, and stiff in other directions. This behavior is very different from that of a normal piezoelectric material such as $BaTiO_3$ or $PbTiO_3$.

installed in Marilyn Fogel's laboratory last September. The new machine—the Ciphergen ProteinChip Reader—is being used to develop the scientific underpinnings to search for biochemical clues of life in the sediments of Mars or the waters of Europa. Tiny amounts of organic matter are bound to the surface of specially modified “chips” in the instrument. The samples are then analyzed by laser desorption coupled to time-of-flight mass spectrometry. Smaller molecules move faster than larger ones, and the instrument precisely measures the arrival time of molecules in nanoseconds to determine the molecular weight.

Living organisms have high molecular weight and complex distributions of organic molecules, which can be easily distinguished from degraded molecular fragments remaining after microbial decay. The ProteinChip Reader can analyze a wide range of molecular weights (100 to 200,000) rapidly and at abundance to as low as 10^{-15} moles.

Marilyn Fogel and James Scott have used the instrument to reveal differences in the protein inventory of the bacterium *Shewanella* MR1 when cultured under different conditions. Robert Hazen and George Cody have used it to examine the organic molecules synthesized in hydrothermal reactions with pyruvate at temperatures up to 250°C.

A new instrument to investigate an old problem: deep seismic boundaries

The interpretation of seismic discontinuities in the Earth's interior requires laboratory data on the properties of Earth materials at high pressures and temperatures. Yingwei Fei has taken advantage of recent advances in a high-pressure multianvil apparatus at the third-generation SPring-8 synchrotron facility in Japan to perform x-ray diffraction measurements of phase transition boundaries in mantle mineral systems under lower mantle conditions. He obtained results on the postspinel transition (spinel = perovskite + periclase) in olivine composition thought to be responsible for the observed 660-km seismic

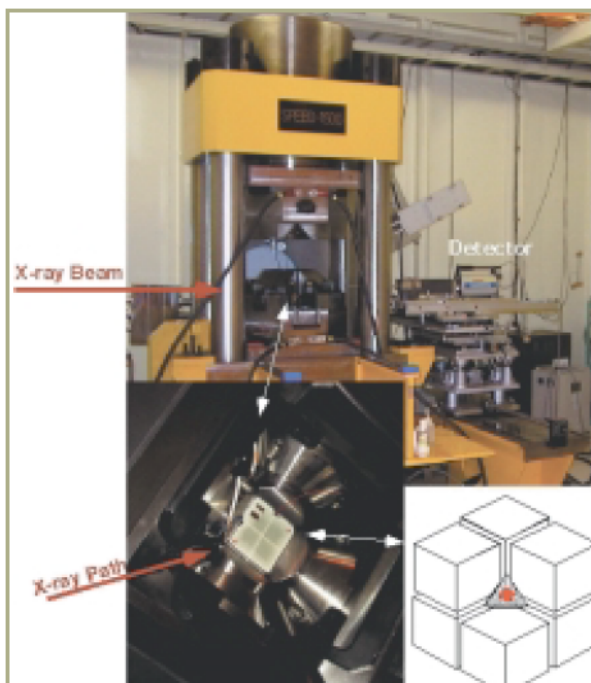


Fig. 7. This 1500-ton hydraulic press at the third-generation synchrotron facility (SPring-8, Japan) allows researchers to perform in situ x-ray diffraction measurements under conditions of the Earth's lower mantle.

velocity discontinuity in the mantle. The results were inconsistent with existing models. Further experiments are planned to resolve this discrepancy. If it cannot be resolved, alternative mantle models may have to be considered, which would have a profound impact on our understanding of mantle petrology and dynamics (Fig. 7).

HPCAT construction at the Advanced Photon Source in full swing

The Geophysical Laboratory, in partnership with the High-Pressure Science and Engineering Center of the University of Nevada, Las Vegas, and the High-Pressure Physics Group of the Lawrence Livermore National Laboratory, has formed the High Pressure Collaborative Access Team (HPCAT), which is currently constructing an integrated high-pressure research facility at the Advanced Photon Source (APS) of the Argonne National Laboratory. This facility will use two

beamlines from the accelerator and novel custom-designed instrumentation to branch these two beamlines into four. This will enable the essentially continuous and simultaneous operation of four experiments in parallel using a range of diffraction and spectroscopic techniques. The APS is a third-generation source of high-energy, high-brilliance photons delivering laserlike beams of x-rays to extremely small samples. Using this source in combination with the diamond-anvil static cell will result in great progress in high-pressure physics, chemistry, materials science, and biology.

Phase I of the HPCAT project will start commissioning experiments in May 2002. When fully completed in early 2003, HPCAT will make available a range of novel instruments allowing integrated x-ray diffraction and spectroscopic studies of samples at high pressure and variable temperatures to researcher members as well as to groups from the national and international high-pressure community.

—Wesley T. Huntress, Jr.



Fig. 8. The new beamline for HPCAT at the Advanced Photon Source accelerator at Argonne National Laboratory is shown here under construction.



Fig. 9. Geophysical Lab Staff Members pictured here in November 2001 from left first row are Marcelo Sepiarsky, Jie Li, Pei-Ling Wang, Shaun Hardy, David George, Charles Prewitt, George Cody, Agnes Mao, Andrew Steele, Maddury Somayazulu, and Yang Ding. Second row from left are Jinfu Shu, Paul Meeder, Sue Schmidt, and Wes Huntress. Third row from left are Bobbie Brown, Yingwei Fei, Nabil Boctor, Merri Wolf, Margie Imlay, Chris Cahill, David Mao, Kamil Dziubek, Rus Hemley, and Ron Cohen. Fourth row from left are Gundmundur Gudfinnsson, John Straub, Yanzhang Ma, Przemek Dera, Steve Coley, Chris Hadidiacos, James Scott, Alex Goncharov, Anurag Sharma, and Viktor Struzhkin. Fifth row from left are Kenji Mibe, Bob Hazen, John Frantz, Yang Song, Eugene Gregoryanz, and Gerd Steinle-Neumann. Sixth row from left are Conel Alexander, Wim Van Westrenen, Bjørn Mysen, Felicitas Wiedemann, Doug Rumble, Shuangmeng Zhai, Mark Frank, and Reed Patterson.

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² To June 30, 2001

³ To September 15, 2000

⁴ To March 10, 2001

⁵ From September 1, 2000, joint appointment with DTM

⁶ To November 15, 2000

⁷ From September 18, 2000

⁸ From April 1, 2001

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¹⁰ From March 1, 2001

¹¹ From February 21, 2001

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¹³ From January 1, 2001

¹⁴ To July 31, 2000

¹⁵ To December 31, 2000, joint appointment with DTM

¹⁶ To August 21, 2000

¹⁷ To August 15, 2000

¹⁸ From October 17, 2000, to June 30, 2001

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²⁸ From January 1, 2001

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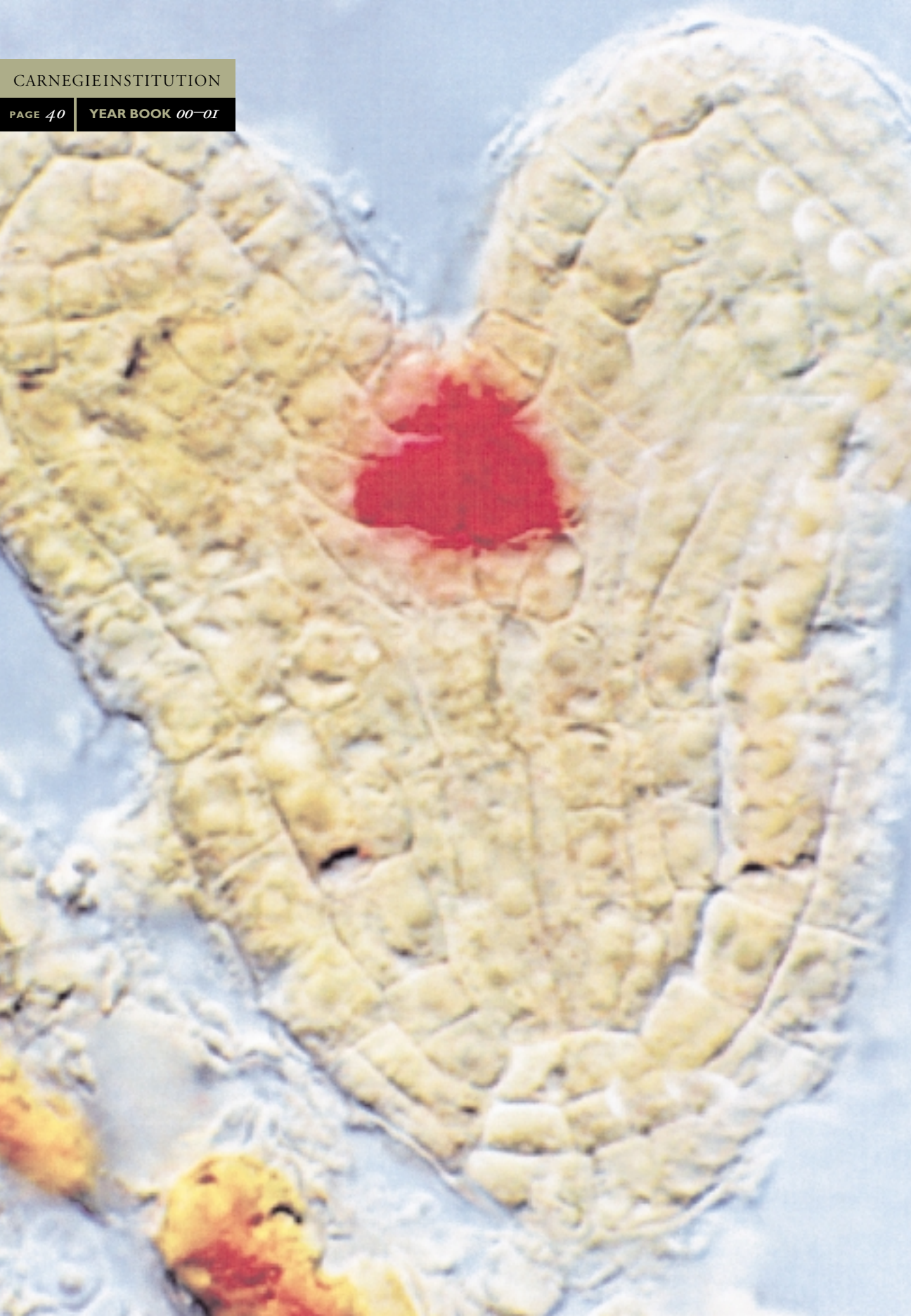
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THE DIRECTOR'S REPORT

"I BELIEVE THAT THE PENDING DIVISION OF THE MOLECULAR AND ECOLOGICAL RESEARCH PROGRAMS INTO TWO DEPARTMENTS WILL ALLOW BOTH GROUPS TO ACHIEVE CRITICAL MASS."

New staff appointments are crucial decisions for any academic department because they provide a tangible commitment to a future direction for the group. In this and related respects the past year was a momentous time for the Department of Plant Biology. A number of new appointments were made, and the trustees approved the formation of a new department—the Department of Global Ecology—which will lead to additional staff changes.

Staff Member Zhi-Yong Wang joined Plant Biology this year following a period of postdoctoral study with Joanne Chory at the Salk Institute. There he explored the molecular mechanisms by which the steroid phytohormone brassinolide affects plant growth and development. Although brassinolide was proposed as a possible growth regulator in the late 1970s, it was not until several groups discovered mutants defective in brassinolide action in the mid- 1990s that their importance as key growth regulators was generally accepted. Mutants unable to synthesize or sense brassinolide are extremely dwarfed (Fig. 1), suggesting that this steroid hormone has an important role in controlling cell expansion and growth. Zhi-Yong's idea about the role of brassinolide relates to the fact that plant cells are normally

very tightly bound to each other by cell-wall components. Thus, when a region of the plant begins to grow and expand it is crucial that all of the cells in the region act in concert so that the cell walls of adjoining cells expand together.

Zhi-Yong believes that brassinolide may act as a general signal of cell expansion that all expanding cells pass to their neighbors to recruit them to act in concert. During the coming years he intends to

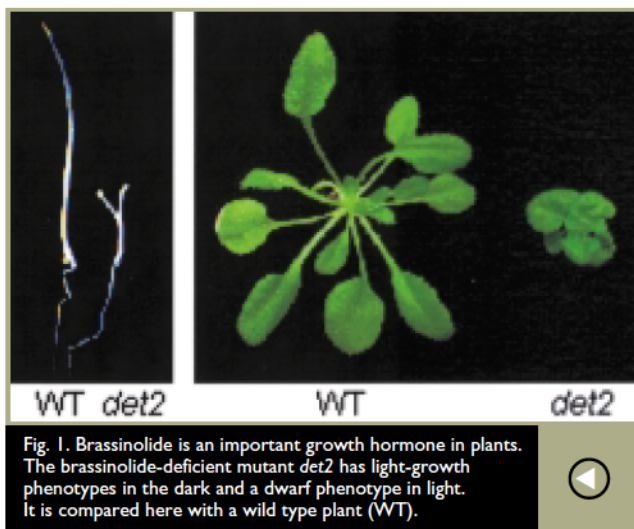


Fig. 1. Brassinolide is an important growth hormone in plants. The brassinolide-deficient mutant *det2* has light-growth phenotypes in the dark and a dwarf phenotype in light. It is compared here with a wild type plant (WT).

Left: Plant Biology's Kathy Barton studies the structure and function of meristems—the undifferentiated stem cells in plants. This is an image of an *Arabidopsis* embryo. The red spot is located at the shoot meristem and indicates where her lab has performed a technique called in situ hybridization to determine where the *STM* gene, which is involved in meristem function, is expressed.

discover how cells sense and respond to brassinolide by characterizing the genes and proteins that are involved using a combination of approaches — molecular genetics and proteomics, or protein characterization. I believe that the eventual understanding of the mode of action of brassinolide will provide a fundamental insight into the most basic level of plant growth control. In addition, I am certain that Zhi-Yong's general knowledge of signal transduction mechanisms will broadly benefit all of the molecular biology research programs in the department.

Zhi-Yong has equipped his new lab with some of the instruments that will facilitate the use of a suite of methods collectively referred to as proteomics. As the name suggests, the technology characterizes proteins. Although methods for this characterization have been widespread for more than three decades, several technical developments have greatly expanded the utility of this analysis. In particular, there are now relatively inexpensive and robust mass spectrometers. These instruments can measure the molecular mass of peptides that are ionized and mobilized from a surface by a pulse of laser energy permitting the identification of a "peptide mass fingerprint" for very small amounts of proteins. Commonly, proteins are separated by two-dimensional gel electrophoresis, then fragmented into peptides and transferred to a solid surface. The peptides are then selectively desorbed by sequentially focusing the laser on the protein spots of interest and recording the masses of the peptides in each spot. This fingerprint can be used to identify any *Arabidopsis* protein by comparing the mass fingerprint with a database of the molecular masses of all possible peptide fragments in the *Arabidopsis* genome. In addition, if some of the peptides are modified by the addition of a phosphate or other types of molecules that may affect the activity or localization of a protein, it is possible to identify the modification. Because many research projects in the department are devoted to problems concerning protein function, the development of proteomic expertise will create many new opportunities for the staff.

A second recent arrival was Staff Member Kathy Barton. Before joining the department, Kathy was an associate professor in the Department of Genetics at the University of Wisconsin. Like many other Staff Members who held university appointments before joining the department, Kathy was attracted to Carnegie because of the opportunity it offered to devote more time to research than is possible as a university faculty member. Her research centers on the molecular mechanisms by which plants generate their bodies. As in other types of multicellular organisms, plants have a cascade of genetic instructions that tell certain cells to divide or not, when to divide, the direction to divide in, the direction to expand, how far to expand, and what type of cell to become. Much of Kathy's research explores apical meristem cells — a group of stem cells that give rise to the body of the plant. Her goals are to understand questions such as what genetic controls define the identity and function of these cells; what controls the rate at which they divide; what defines how many cells share the same identity; and how the identity of the cells changes at the perimeter of the meristem as leaves form from former meristematic cells. By isolating and analyzing mutants with altered meristem function, she has defined several of the genes that appear to be near the origin of a cascade of regulatory switches controlling meristem function. The most completely characterized of these, a gene called *shoot meristemless*, or *STM* (Fig. 2), appears to encode a transcription factor — a class of proteins that control the expression of genes. Understanding how the activity of *STM* is controlled, and what genes are controlled by *STM*, will provide a deep insight into one of the most fundamental mechanisms underlying plant growth.

Since all flowering plants have recently evolved from a common ancestor, it seems likely that the enormous morphological diversity that we find in the natural world reflects variations on a basic set of similar instructions. By understanding the basic rules that govern plant growth and development in a few plants, we may be able to understand how diversity originates and how to create novel types of plant morphology that might be useful. For instance, one of the key elements of the green

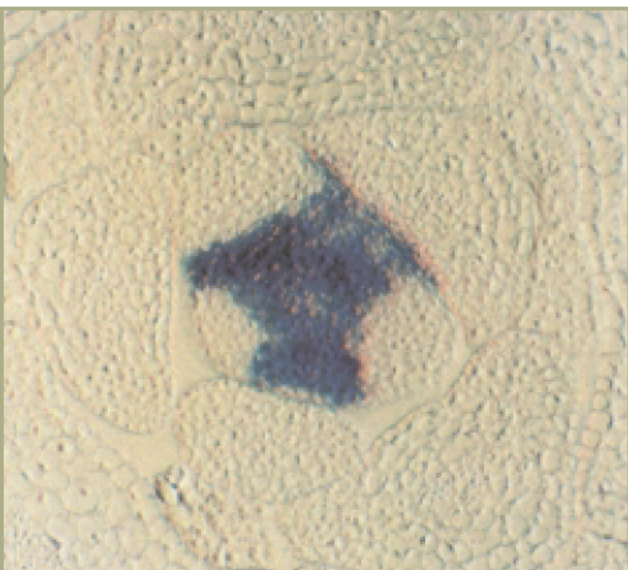


Fig. 2. This is a transverse section through an apical meristem of an *Arabidopsis* shoot. The meristem produces leaves in a spiral pattern. New cells used to form these leaves are generated by a small number of stem cells located in the center of the meristem. An early and critical step in leaf development is down-regulation of the *shoot meristemless* transcript, which is detected here by *in situ* hybridization in which the cells expressing the gene are stained blue.

revolution was the identification of a gene that regulates the division and expansion of cells in cereal stems. By breeding cereals with fewer and smaller cells in their stems, plants resulted that devoted less photosynthate to stem growth and more to reproductive growth (i.e., grain production). I believe that as our knowledge of plant development expands there will be many more opportunities to create plants with improved yield by directly modifying the basic process of growth and development. I am particularly intrigued by the fact that although *Brassica napus* and *Arabidopsis* have very similar morphology and are very similar at the DNA level, *B. napus* becomes a plant with hundreds of times the biomass of an *Arabidopsis* plant. Perhaps by learning the molecular basis for the size difference, we will be able to discover why some plants are large and grow rapidly and others are small and grow slowly. Such knowledge would create new opportunities to unlock the yield potential of many currently underused plant species. Although it will be years

before we know the basis for the large difference in size between these species, I believe that Kathy Barton's work on meristem function will be an important component of the eventual explanation.

Two other additions to the department this year were the appointments of Devaki Bhaya and Matt Evans as adjunct Staff Members. The adjunct position is a new type of appointment in which the department hosts scientists with independent research programs that are largely supported by external funding. It is our hope that the incumbents in these positions will benefit from access to the Plant Biology facilities and, at the same time, contribute their expertise, insights, and energy to the scientific life here.

Devaki investigates cyanobacterial phototaxis, a process by which cyanobacteria normally move toward or away from light. She recently demonstrated for the first time that phototaxis in *Synechocystis* is a surface-dependent phenomenon that requires type IV pili. These pili are long surface appendages implicated in the association of bacterial pathogens with their hosts and with twitching and social motility. By characterizing a collection of mutants that fail to respond to light, or that respond negatively to it (i.e., they move away from the light source), Devaki intends to define the mechanisms by which these ubiquitous photosynthetic organisms sense and respond to light.

One of the mutants Devaki characterized has a lesion in a chemoreceptor-like protein with a domain that is reminiscent of the chromophore-binding domain of phytochrome in vascular plants. This novel protein may be a photoreceptor involved in the complex signal-transduction process between light perception and optimal conditions for photosynthesis. At present, it appears that some components of the response mechanisms are similar to those used by other bacterial species for chemotaxis. Other components of the response mechanism are encoded by novel genes that do not appear to have counterparts in nonphotosynthetic bacteria. These components may be involved in coupling perception of light to

motility. The mechanisms by which light is converted to directional signals promise to be unique. It will be fascinating to learn, during the coming years, the extent to which the processes used by cyanobacteria since before land plants arose have evolved into the kinds of photoresponsive activities studied by Winslow Briggs in his pursuit of determining how plants undergo phototropism in response to blue light.

Matt Evans's research looks at defining certain genes that are specifically required for plant reproduction. Plant gametes — the sperm and egg cells — are produced by stereotypical division that convert a single diploid cell (in a diploid plant) into several haploid cells. Fusion of a sperm and an egg following pollination leads to the formation of a diploid embryo. Simultaneously, the fusion of a second sperm cell with a second female gamete — the central cell — leads to the formation of the endosperm, then nutritive tissue of the seed and the bulk of the grain weight in cereals such as maize, rice, and wheat. Several lines of evidence suggest that gene expression by the female gametophyte, or megagametophyte, is required for successful fertilization and subsequent development of a seed from the fertilized megagametophyte. However, the identity and function of most of these genes are not known.

In order to identify these genes, Matt has identified several mutations in maize that cause abnormal kernel development when these seeds inherit the mutation from the maternal gametophyte. These mutants fall into two general classes: those with an abnormal megagametophyte morphology that secondarily leads to abnormal kernel development, and those with normal megagametophyte morphology that lead to abnormal progeny. Three mutants have been identified in the first class and are recurrently being characterized in greater detail. Three mutants have also been identified in the second class. These mutations cause various abnormalities in embryo or endosperm development, but they are difficult to interpret without knowing when and where the corresponding genes are expressed and what the function of the gene product are. Some of the

mutations were isolated from a population of plants in which the transposable element *Mutator* is active. Thus, there is a good chance that the mutations are due to the inactivation of a gene by the insertion of a transposed *Mutator* element, which will greatly facilitate the cloning of these genes. Other cloning strategies are being pursued for the mutations that arose in the lines without active *Mutator* elements. It will be very interesting to learn what kinds of functions have been relegated to control by the haploid genomes. So little is currently known about this aspect of seed development that it is difficult to predict what the implications of this knowledge may be. However, since seeds form the vast majority of the food supply, it is essential to explore this difficult-to-study aspect of the overall process.

The appointments of these four new colleagues will significantly reshape the department for many years to come. They also reflect a significant departure from the past emphasis on photobiology and adaptation toward an expanded interest in growth and development. But what of physiological ecology, one of the great strengths of the departments since the days of Clausen, Keck, and Hiesey? I am happy to report that this strength is destined for expansion. In anticipation of the pending 100th anniversary of the Carnegie Institution, President Maxine Singer convened a series of workshops in which many of the leading thinkers in various areas of science were invited to comment on the future opportunities in science. One of the outcomes of this process was a consensus that the general area of global ecology was likely to be of great scientific importance during the foreseeable future. This consensus, in turn, led to a commitment by the board of trustees to support an expansion of the global ecology program currently represented within the department by the work of Chris Field and Joe Berry. In addition, the Mellon Foundation pledged \$1.2 million to support an expanded global ecology effort at Carnegie. The current plan is to create the Department of Global Ecology within the coming year. The new entity will be located on the same site at Stanford University with Plant Biology, but will be autonomous within the

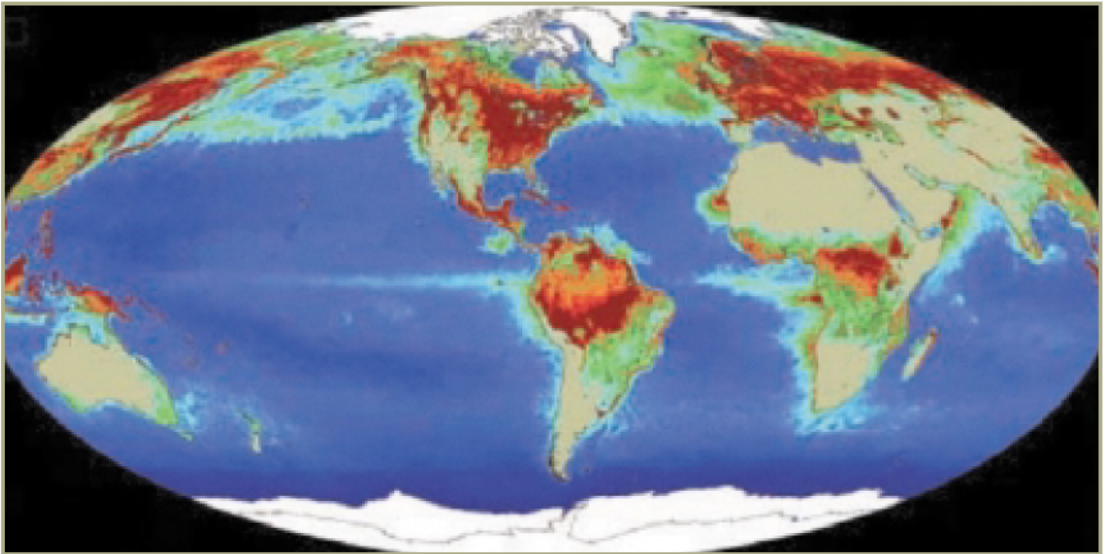


Fig. 3. Researchers in the new Department of Global Ecology are harnessing tools, such as the SeaWiFS (Sea-viewing Wide Field-of-view Sensor) satellite, to study the ecological processes on Earth from the molecular scale to the scale of the entire planet. This image shows the amount of plant growth, or net primary production (NPP), in the summer months for the years 1997 to 1999 (Image reprinted with permission from *Science* 291, p. 2596. Copyright American Association for the Advancement of Science.)

Carnegie Institution. It is the first new department in over 80 years.

Chris Field and Joe Berry will be the founding members of Global Ecology. In anticipation of the new department, we also recently appointed a new Staff Member, Greg Asner. Greg, who is an assistant professor at the University of Colorado, will be the third faculty member in the new department. I believe that the pending division of the molecular and ecological research programs into two departments will allow both groups to achieve critical mass, something that has been difficult to accomplish with the limitations on the number of staff in one department. The continued coexistence of the two groups at the same site will also facilitate collegial interactions between the groups wherever scientific opportunities exist in the interface between the two disciplines.

—Christopher Somerville

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 Arthur R. Grossman
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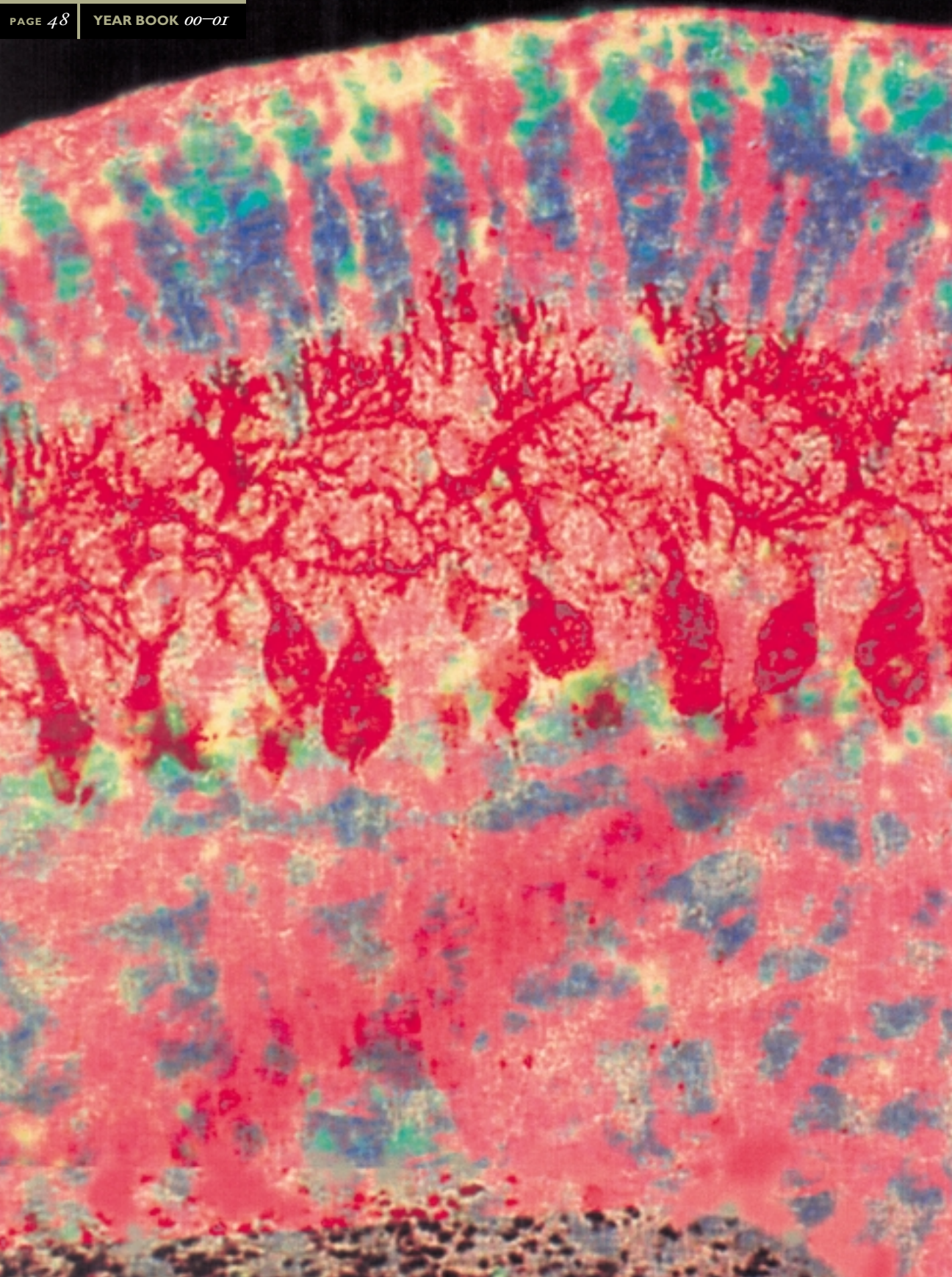
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¹ From June 15, 2001² From June 16, 2001³ From January 15, 2001, to June 2, 2001⁴ To July 9, 2001⁵ From October 1, 2000⁶ To August 31, 2000⁷ To September 7, 2000⁸ From March 5, 2001, to April 10, 2001⁹ To December 31, 2000¹⁰ To June 31, 2001¹¹ From February 5, 2001¹² From April 1, 2001¹³ From September 15, 2000¹⁴ To July 15, 2000¹⁵ From May 1, 2001¹⁶ To August 17, 2001¹⁷ To June 30, 2001¹⁸ To June 4, 2001¹⁹ To April 30, 2001²⁰ From August 1, 2000²¹ From December 1, 2000²² To August 15, 2000²³ From September 15, 2000, to June 15, 2001²⁴ From January 15, 2001, to June 22, 2001²⁵ To July 9, 2000²⁶ To July 5, 2000²⁷ From August 1, 2000, to October 31, 2000²⁸ From February 12, 2001²⁹ To June 30, 2001³⁰ From April 14, 2001³¹ To February 15, 2001³² From April 23, 2001, to June 15, 2001³³ From January 18, 2001³⁴ From July 1, 2000, to August 25, 2000³⁵ From July 5, 2000³⁶ From August 30, 2000³⁷ From October 1, 2000³⁸ From November 1, 2000³⁹ From January 15, 2001, to March 31, 2001⁴⁰ From January 15, 2001⁴¹ To May 31, 2001⁴² From January 1, 2001⁴³ To June 30, 2001⁴⁴ From August 7, 2000⁴⁵ From April 3, 2001⁴⁶ From March 14, 2001⁴⁷ From July 25, 2000⁴⁸ To November 30, 2000⁴⁹ From January 13, 2001⁵⁰ To August 15, 2000⁵¹ To December 31, 2000⁵² From February 1, 2001⁵³ From March 26, 2001, to June 30, 2001⁵⁴ To June 30, 2001⁵⁵ To July 31, 2000⁵⁶ From July 10, 2000⁵⁷ From April 11, 2001⁵⁸ From July 1, 2000⁵⁹ To June 30, 2001⁶⁰ From July 24, 2000, to October 31, 2000⁶¹ To August 31, 2000⁶² From May 29, 2001⁶³ From July 12, 2000, to September 15, 2000⁶⁴ To July 30, 2001

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THE DIRECTOR'S REPORT

"NEW FACILITIES CAN PROVIDE NEW OPPORTUNITIES AND STIMULATE A NEW ROUND OF RISK TAKING BY THE STAFF."

Scientists not only question nature, they also constantly second-guess their own research strategy. How much effort should be expended on current projects, and how much should be devoted to developing a new area or technique? The lure of a long-term investment is great. Beginning anew, acquiring and applying novel instrumentation, and interacting with new colleagues tremendously invigorates one's research program — indeed one's whole outlook on life. Yet there are costs to be paid. Each new venture, initially at least, drops productivity below familiar levels. While the decline may only be temporary, there is no guarantee that a new venture will succeed or bear fruit at all. At worst, switching direction can be a warning that a research program's frontier and ideas have run their course. With these thoughts in mind, each research group continually weighs the prospect of an almost unlimited number of possible new directions and collaborators. Ultimately, the calculus of decision not to take some routes and decline others goes along way toward defining a scientist's career. One senses that consistently productive and innovative researchers usually are able, on at least a number of occasions,

to make dramatic changes successfully in their subjects and methods of study.

This same challenge applies to departments as a whole. Laboratory facilities must be renewed periodically to ensure that a abundant opportunities remain available in the long term to individual investigators. Indeed, new facilities can provide new opportunities and stimulate a new round of risk taking by the staff. However, designing and building a new laboratory inevitably impedes ongoing research. As plans for a new home for the Department of Embryology move forward — a process in which all our staff actively participates — we are confident that we have found a proper balance. Because the building will occupy a new site, current operations are only minimally affected, allowing us to remain focused on the many advantages the new building will offer for our continued success in future years. We anticipate the ability to sustain new colleagues and collaborations by the addition of laboratory space for Staff Associates and visiting scientists. We are eager to see improvements in our infrastructure that will enable us to expand our genetic resources,

Left: Chen-Ming Fan uses the mouse to study the genetics involved in mammalian development. This image shows the stereotypic layered organization of a developing cerebellum in the mouse. The top green layer is the proliferating granule stem cells; the blue cells below them are the differentiating granule cells. Pink fibers through the granules are the Bergmannian fibers, which guide the differentiating granule cells to climb down into the inner chamber. The dark trees with bulbs are the Purkinje cells, to which the granule cells make connections. They yellow cells between the bulbs are the proliferating Bergmannian stem cells. The granule cells and the Purkinje cells work together to modulate fine body motor activity. (Courtesy Chen-Ming Fan.)

support more sophisticated microscopes, and better analyze the avalanche of data we generate and import from diverse sources. Most important, we have made a special effort to ensure that the new building will maintain and enhance the atmosphere of collegiality and interactivity that is our biggest scientific asset.

Ironically, even the organisms we study face similar choices of short-term versus long-term investment via the evolutionary process. For example, producing a vertebrate nervous system—the most complex construction project known—requires an extensive period of embryonic development before any documented benefits can be received. Several laboratories, including those of Chen-Ming Fan, Marnie Halpern, and Jimo Borjigin, continue to study this fascinating process, whose stages and key construction milestones have yet to be fully described at the molecular level. Fan's group recently characterized a gene known as *Gas1* and showed that it is involved in controlling and coordinating the post-natal growth of two cell types in the cerebellum (Fig. 1). Halpern is studying a growing collection of genes that activate differentially on the left or right side of the brain (Fig. 2). These studies promise to reveal more about how and why left and right brain hemispheres specialize for different functions. Borjigin has been studying the role of the pineal gland, the key circadian neuroendocrine regulator of body function. Her lab has developed a novel automated microdialysis system that allows real-time sampling of pineal secretions in vivo, work that has already revealed new insights into the regulated production of serotonin, precursor of the pineal hormone melatonin.

Most animals continuously renew their bodies to avoid the challenges of periodically constructing and moving into new ones. The raw materials for such repair and replacement are cells at an early state of differentiation, a resource that is abundant only in early embryos. Immature cells are supplied in adults at the proper time, place, and amount by the spatially and temporally regulated division of stem cells. These special, rare cells, dispersed throughout the body, can divide without apparent

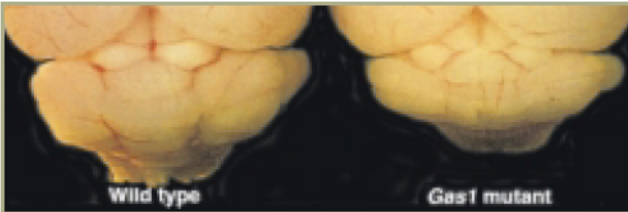


Fig. 1. The cerebellum is the folded horizontal structure at the bottom of each brain in this image. As shown, *Gas1* mutant mice have a half-size cerebellum (right) compared with normal mice. The main cause of this defect is reduced cell proliferation and excessive cell death of the granule and the Bergman glia stem cells. These are the two main cell types produced postnatally in the cerebellum. Cerebellar granule cells constitute about 80% of the neurons in the entire brain.

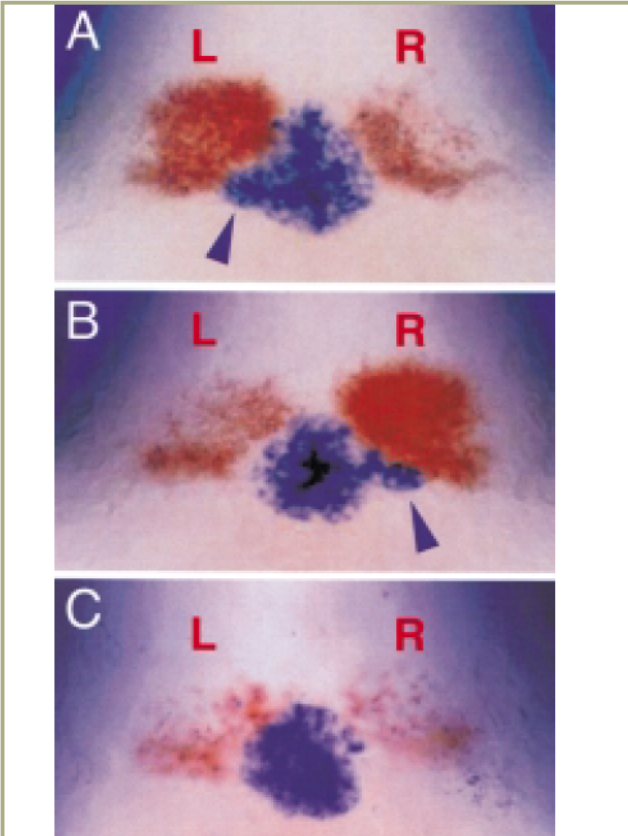


Fig. 2. This series of images supports the hypothesis that the parpineal directs the sidedness of the dorsal habenular nucleus—the nucleus in the stalk of the pineal body of the brain. The Halpern lab uses the zebrafish in such studies. In the zebrafish epithalamus (A), the parpineal (blue arrowhead) is typically located to the right of the pineal organ, adjacent to the left habenular nucleus (L). In some larvae (B), the molecular asymmetry of the habenulae (red) is reversed when the parpineal shifts to the right side of the brain. Laser ablation of the parpineal earlier in development prevents this asymmetry (C). (Courtesy J. Gamse.)

limit and differentiate into a wide variety of cell types, while at the same time renewing their own numbers. Stem cells pose many of the same fundamental developmental questions as early embryos, but at present they are much less well understood. Enhancing normal stem cell activity is also thought to hold great therapeutic promise.

This year Erika Matunis and her co-worker Natalia Tulina reported significant progress in understanding one of the signals regulating stem cell activity in the *Drosophila* testis. Although they produce far fewer sperm than mammals, fruit flies maintain a ready supply of male gametes by controlling the division of germ line stem cells (gscs) located near a special set of nondividing differentiated cells called hub cells. Matunis and Tulina showed that a signal encoded by the *unpaired (upd)* gene is produced in hub cells and received in gscs. When the upd signal or its reception is blocked by mutation, stem cells cease dividing (Fig. 3). Analogous genes and signals are present in many other organisms and it will be interesting to learn if some carry out related functions. Studies of female germ line stem cells in the Spradling lab and studies by Phil Newmark and Alejandro Sánchez of the multipotent flatworm stem cells called neoblasts will further advance the search for common molecular pathways in stem cells.

Even as planning for the new building progresses, we continue to upgrade research tools in our current home. This year we added a new confocal microscope that is able to acquire data at a high rate by employing a "spinning disk" mechanism. This instrument has become our most completely computer-controlled microscope. It is possible to program it to automatically take a complex series of images over many hours or days, providing a truly four-dimensional picture of developing cells and tissues. This technology really comes into its own when combined with new techniques that allow specific gene products to be tagged with different-colored fluorescent markers. Following the relative location and behavior of multiple gene products during developmental processes provides a highly versatile and informative window on bio-

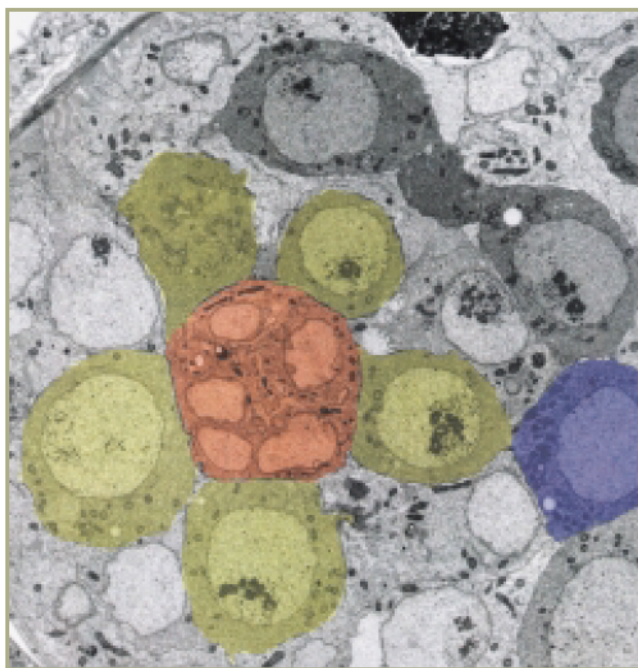


Fig. 3. This electron micrograph from the Matunis lab shows stem cell regulation in a *Drosophila* testis. The red cell is the hub. The surrounding five green cells are stem cells, and the blue cell is a daughter cell that has moved away from the hub. The scientists believe that the hub sends signals to the stem cells to remain stem cells, while the daughter cell becomes a differentiated cell because it is away from the hub and does not receive the signal. (Courtesy Erika Matunis.)

logical mechanisms that many in the department are eager to exploit. Staff Associate Terence Murphy has already become expert with the instrument and is teaching a series of classes on its use for different levels of users.

News of the Department

Our seminar program was highlighted by the 24th annual minisymposium, entitled "Organelle Biogenesis." Jodi Nunnari (University of California, Davis), Robin Wright (University of Washington), Steven Rodermeil (Iowa State University), Stephen Gould (Johns Hopkins School of Medicine), David Roos, (University of Pennsylvania), and Graham Warren (Yale University) presented one-hour talks.

Support of research in the department comes from a wide variety of sources. Doug Koshland, Yixian

Zheng and I, and various members of our laboratories are employees of the Howard Hughes Medical Institute (Fig. 4). Others are grateful recipients of individual grants from the National Institutes of Health, the John Merck Fund, the G. Harold and Leila Y. Mathers Charitable Foundation, the American Cancer Society, the Pew Scholars Program, the National Science Foundation, and the Helen Hay Whitney Foundation. We also remain indebted to the Lucille P. Markey Charitable Trust for its support.

—Allan C. Spradling



Fig. 4. Members of the Staff of the Department of Embryology. Front row (from left): Christine Norman, Cathy Mistrot, Eileen Hogan, Andy Fire, Chen-Ming Fan, Tim Mical, Bob Levis, Joe Gall, Alexi Tulin, Heather Henry, Don Brown, Tom McDonough, Ararat Ablooglu, Toshi Kai, Alice Chen, Elein Unal. Second row, seated: Doug Koshland, Erika Matunis, Allan Spradling, Horacio Frydman, Eva De Cotto, Audrey Huang, Bonnie Kargar, Korie Handwerker, Yun Xu. Second row, standing: Ona Martin, Hui Jin, Liquan Cai, Chunqiao Liu, Kan Cao, Jimo Borjigin, Ru Gunawardane, April Lowrey, Mike Sepanski, Alex Schreiber, Josh Gamse. Third row: Pat Cammon, Rachel Cox, Melissa Pepling, Daniela Barbosa, Ella Jackson, Ellen Cammon, Glenese Johnson. Fourth row: Terence Murphy, Jim Wilhelm, Christian Broesamle, Michelle Macurak, Tiecheng Liu, Rachel Brewster, Laurel Mellinger, Chris Murphy, Hong-Guo Yu, Natalia Tulina, Biswajit Das, Allen Strause, Shin-ichi Kawaguchi, Ky Sha, Zheng-an Wu, Olivia Doyle, Dongli Huang, Mark Milutinovich, Ronald Roane, Warren Hall, Kristie Lomangino. (Courtesy Kris Belschner.)

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THE DIRECTOR'S REPORT

Magellan Arrives

In August 2000, the primary mirror of the Baade telescope (also known as Magellan I) was hoisted into the aluminization chamber located in the Magellan Auxiliary Building, the filaments were fired for 28 seconds, and a not perfect but quite acceptable coat of aluminum was evaporated onto the surface. On September 15, 2000, the primary mirror thermal control system, which is essential to maintain the figure of the mirror, was turned on for the first time, and the Baade telescope saw first light. Present for this occasion were Matt Johns, Steve Sheckman, Frank Perez, and a host of Las Campanas Observatory (LCO) and Magellan technical staff. Using the one and only working guide camera as an instrument, images as good as 0.52-arc-seconds (full-width half-maximum) were obtained. Given that the active optics system, which tunes the shape of the primary mirror, was not yet working, this was a remarkably good start.

Over the following few months the active optics system was brought into operation with much help from Paul Schechter of MIT. Finally, on December 4, 2000, the Baade telescope was used for the first time with a science instrument (one of the Las Campanas CCD cameras) that could deliver the full image quality of the telescope. That night, images as good as 0.34-arc-seconds were obtained. Little more was done in December except prepare for, and recover from, what was undoubtedly the best party ever held in the Atacama Desert: the Magellan dedication (Fig. 1).



Fig. 1. On December 9, 2000, the Baade and Clay telescopes, the Green-Pappalardo Science Support Facility, the John Stauffer Library, and the Horace Babcock Lodge were all dedicated in a ceremony at Las Campanas. (Courtesy Hernán Contreras.)

More than 350 people from Chile, the U.S., and elsewhere turned out for this event, which featured songs by Chilean schoolchildren, string quartets, many speeches, and a wonderful feast, followed by viewing through the Baade telescope.

Routine operations began on February 14, 2001, with a run by astronomers from the University of Arizona. Since then, the Baade telescope has been used for science on about 70% of the available clear nights. The remaining time has been used for various engineering tasks. The telescope's performance has been nothing less than spectacular. The brilliant image quality, which was apparent from

Left: This is a color composite from the the Las Campanas Infrared Survey, which is an optical survey to study galaxy evolution. The halos around the bright stars appear green. (Courtesy Hsiao-Wen Chen, Alan Dressler, Patrick McCarthy, Augustus Oemler, Jr., Eric Persson and collaborators.)

the first observations, has continued. Although adequate statistics have not yet been obtained, it appears that the telescope is able to take advantage of whatever seeing the site provides. The best images to date have been better than 0.28-arc-seconds, and seeing of 0.5-arc-seconds is quite common. Equally remarkable has been the reliability of the entire system: only about 6% of time has been lost to technical problems, much less than one expects during the first months of operation.

Only one thing limits the productivity of the Baade telescope at this time—the lack of an adequate suite of instrumentation. The first facility instrument, the CCD imager MAGIC provided by MIT and Harvard, was delivered in the spring of 2001. However, the other first-generation facility instruments, the IMACS and MIKE spectrographs, and the PANIC infrared camera, are not expected until mid-2002. In the meantime, we are making do with a collection of begged and borrowed substitutes, including the LDSS-2 spectrograph from the William Herschel Telescope, and a motley collection of cameras and spectrographs scrounged from the du Pont and Swope telescopes.

With less than the best instruments, and with less than all of one telescope available, it has been too early to begin major observational programs. Most of the staff and fellows have used their first few Magellan nights to explore what the telescope can do, and to take the first preparatory steps toward the large-scale programs that will absorb most of Carnegie's share of Magellan time. Nevertheless, even the snippets of science that have already been accomplished illustrate what the telescopes will be able to do, and what kinds of things Carnegie astronomers will do with them.

First Science

The Year Book 99/00 described the search by George Preston, Steve Szeftman, Andy McWilliam, and Ian Thompson for extremely metal-poor stars in the halo of our galaxy. Such stars are survivors from the first stages of galaxy formation, and their chemical composition has

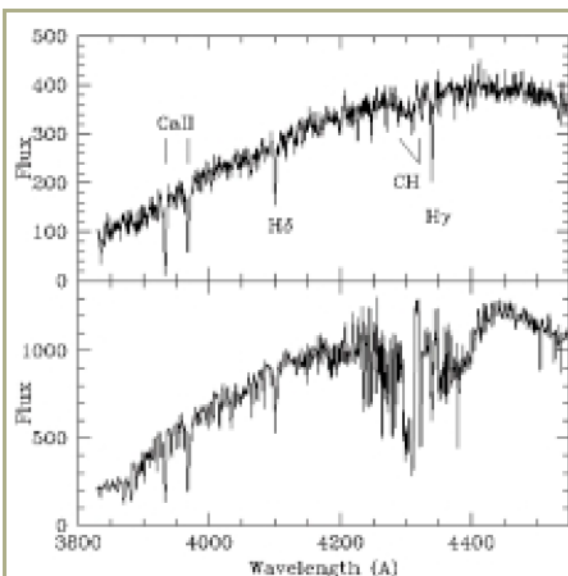


Fig. 2. This image contains the spectra of two extremely metal-poor stars obtained by Andy McWilliam on the Baade telescope. The differences in the strengths of the CH molecular bands illustrates the great degree of chemical inhomogeneity in the early history of our galaxy.

much to tell about the mechanisms and history of chemical enrichment. Magellan spectroscopy of stars found in this survey has now begun. Figure 2 illustrates the spectra of two such stars, with very similar and very low metal abundances of about 1/1600 that of the Sun. The data were obtained with the B&C spectrograph on the Baade. The spectra of such very metal-poor stars usually only show hydrogen and calcium lines, as in the upper panel. By contrast, the star in the lower panel shows strong molecular bands due to CH, despite the similarity in hydrogen and calcium line strengths. This indicates that there is a huge variance in the carbon content of extremely metal-poor stars, and suggests that the early galactic halo was chemically quite inhomogeneous.

There is mounting evidence that many galaxies grew from smaller units, and that galactic mergers may have played a major role in determining the shapes and dynamics of—at least—elliptical galaxies. However, the details of this assembly process remain unclear, and there are several competing hypotheses for the formation of ellipticals. Fortunately, a few galactic mergers still occur in

the local universe and offer valuable clues to such past assembly. The discovery that globular star clusters form in profusion during mergers of gas-rich galaxies has opened new avenues to studying the formation and evolution of both these clusters and their host galaxies.

François Schweizer and Patrick Seitzer (University of Michigan) have used the LDSS-2 spectrograph on the Baade to obtain multi-slit spectra of 35 candidate globular clusters in the recent merger remnant NGC 7252 (Fig. 3) and 68 clusters in the peculiar elliptical NGC 1316. These spectra will yield metallicities and more accurate ages for at least the brighter clusters in these key systems, which are about 500 million and 3 billion years old, respectively. Measurements of radial velocities of individual clusters will permit comparative studies of the kinematics of metal-poor and metal-rich globulars within the same galaxy. This should provide valuable clues about the origins of what are thought to be first- and second-generation cluster subpopulations.

The bending of light by the gravitational fields of massive galaxies or clusters of galaxies can produce distorted or multiple images of galaxies located behind the massive object. The amount and character of this lensing can provide the best measurement of the mass of the foreground galaxy or cluster; and this technique has become one of the most effective methods of mapping dark matter. Using the Baade telescope, Luis Ho and Swara Ravindranath have observed the particularly massive cluster of galaxies RX J1347-1145 containing multiple “arcs” of gravitationally distorted background galaxies (Fig. 4). They have confirmed a previously reported redshift for one arc and set significant limits on the redshift of others, a first step toward using these arcs to measure the mass distribution in this very interesting cluster.

When single galaxies lens background quasi-stellar objects (QSOs), the time of travel of the light that produces the multiple images can differ by months or years. If the QSO is variable, one can measure this difference in travel time along the different paths and thus determine the difference in distance. This gives one the scale of the system,

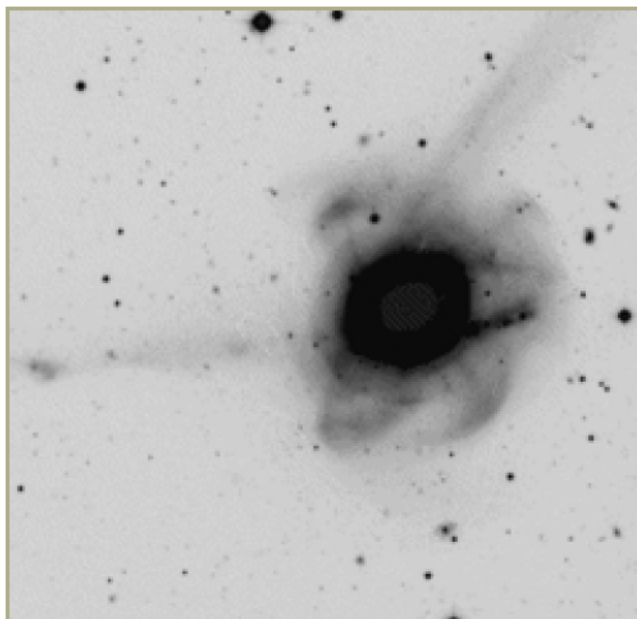


Fig. 3. The recent merger remnant NGC 7252 features many relatively young (400 million to 600 million years old) globular clusters in its halo. Spectroscopy of these clusters can help unravel the history of the merger events. (Image in visual light obtained in 0.8-arc-second seeing at the du Pont 2.5-meter telescope.)

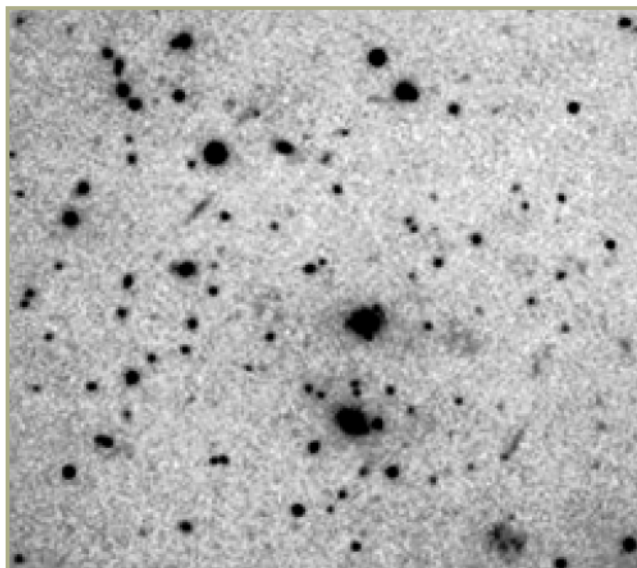


Fig. 4. An image of the cluster RX J1347-1145 taken with LDSS-2 on the Baade is shown here. Two prominent gravitational arcs of background galaxies surround the bright central galaxy at 10 o'clock and 4 o'clock.

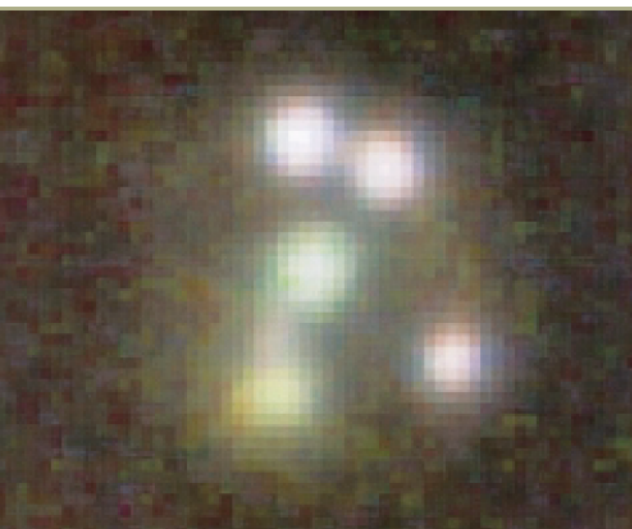


Fig. 5. This is a three-color infrared image of a lensed QSO, obtained by Mark Phillips on the Baade telescope. Four images of the QSO surround a pair of galaxies responsible for the lensing.

and—together with the redshifts of the objects—provides the numbers needed to calculate the Hubble constant in a very different manner from that employed in conventional methods (for example, as described in Wendy Freedman's essay in the Year Book 98/99). Mark Phillips has obtained infrared images in half-arc-second seeing on the Baade of one such system, which is being studied by Paul Schechter (MIT). The multicolor infrared image is shown in Fig. 5. Three bright and one faint image of the background QSO surround a pair of lower-redshift galaxies whose massive halos are producing the imaging.

Galaxy clusters are the most massive bound systems in the universe, and are a critical test environment both for theories of galaxy formation and for theories of structure formation and cosmology. A collaborative project (between Carnegie Fellow Mike Gladders and astronomers at the University of Toronto and the Universidad Católica) now under way at the Magellan telescopes aims to exploit this fact by studying a large sample of distant clusters selected from the recently completed Red-Sequence Cluster Survey. Imaging and spectroscopy of these systems will allow measurements of their mass and galaxy

composition, and hence constrain the epoch and process by which these most massive systems assemble. An example image of one target in the study is shown in Fig. 6. This newly discovered cluster is one of a handful known at such great distances, and judging from recent work using Magellan, appears to be the most massive of these extremely distant objects.

Gamma-ray bursts are the most energetic objects in the universe. For a brief time, they outshine even the most luminous supernovae or QSOs and can be seen anywhere in the visible universe. They are thought to be due, like some supernovae, to the collapse of massive stars, but our understanding of them is very primitive. Because they are very short-lived, fading in hours or days, rapid follow-up observations with large telescopes, after they are first detected by gamma-ray survey satellites, are essential for unraveling their nature. Figure 7 shows observations at Las Campanas of a recent distant gamma-ray burst. In the first 48 hours after the burst, the optical afterglow could be detected with the du Pont 2.5-meter telescope. However, only a few days later the object had faded from reach of the du Pont, and six days after that it was at the

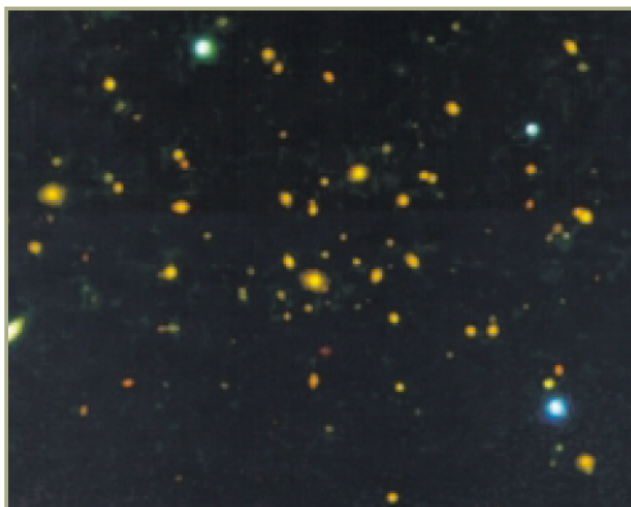


Fig. 6. This is an image of the newly discovered distant galaxy cluster RCS0439-29. The image is composed of infrared green and blue images from the VLT and Baade telescopes. Recent work with Magellan has also spectroscopically confirmed the cluster redshift at $z = 0.96$, making it one of the most distant clusters known.

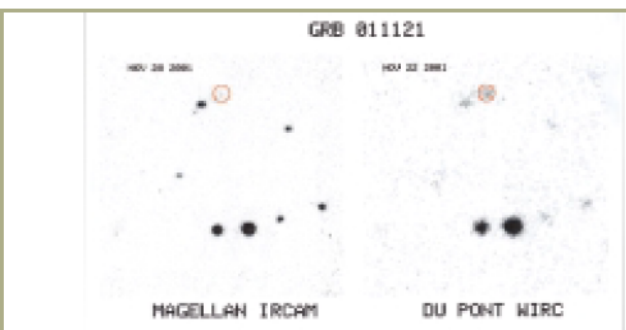


Fig. 7. Images of the rapidly fading gamma-ray burst GRB 011121, observed on the du Pont and Baade telescopes, are shown here. Seeing in the Baade image is about 0.5-arc-second.

limit of the Baade infrared camera. These observations of the rate of decay of the optical fireball, particularly at late times, are critical to our understanding of the jets of relativistic plasma thought to be responsible for the observed radiation.

Meanwhile, Elsewhere on the Mountain

While the Baade telescope begins doing science, the Clay telescope (Magellan II) approaches first light. The enclosure was completed, and the telescope mount erected within. The University of Arizona Mirror Lab finished the polishing of the primary mirror early in 2001, and shipment to Chile was scheduled for midyear. It is expected that the telescope optics will be installed in early 2002, with scientific operations beginning in the second half of the year. One might expect the second telescope's commissioning to go even more smoothly than the first. However, the staff commissioning the Clay telescope is the same as the one that operates the Baade; the constraints imposed by a limited number of people will probably determine the schedule.

Down the hill from the Magellan telescopes, the Astronomer Support Building—now adorned with the name Cecil and Ida Green and Neil and Jane Pappalardo Science Support Facility—neared completion in June 2001 (Fig. 8). Soon, the Las Campanas technical staff will move from their windowless crypt in the du Pont dome to much



Fig. 8. The Green-Pappalardo Science Support Facility will house laboratories, shops, technical staff, visiting and resident astronomers, and the John Stauffer Library. The Baade and Clay telescopes can be seen on the hill above.

more spacious and convenient quarters. In addition to electronics and instrument labs and a machine shop, the support building has offices for technical staff and resident and visiting astronomers, and houses the John Stauffer Library. Another dorm for astronomers was also completed and is already filled with new staff and users. One more is being planned.

—Augustus Oemler, Jr.
Crawford H. Greenewalt Director

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July 1, 2000 – June 30, 2001

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Jorge Estrada, Electronics Technician¹⁰
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Yerko Aviles, Administrative Assistant
Hector Balbontin, Chef
Carlos Callejas, Mountain Superintendent
Pedro Camizo, Plumber
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Stuart Vogel, University of Maryland
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John Webster, Durham University, England
Ben Weiner, University of California, Santa Cruz
Kyle Westfall, University of Virginia
Howard Yee, Universidad Católica, Chile
Ann Zabludoff, University of Arizona
Dennis Zaritsky, University of Arizona

¹ From August 14, 2000

² From October 4, 2000

³ To July 31, 2000

⁴ From September 1, 2000

⁵ To September 5, 2000

⁶ To November 12, 2000

⁷ To January 1, 2001

⁸ To June 8, 2001

⁹ From June 4, 2001

¹⁰ From April 9, 2001

¹¹ To June 6, 2001

¹² To August 31, 2000

¹³ From August 1, 2001

¹⁴ To May 9, 2001

¹⁵ From October 23, 2000

¹⁶ To October 4, 2000

¹⁷ To January 14, 2001

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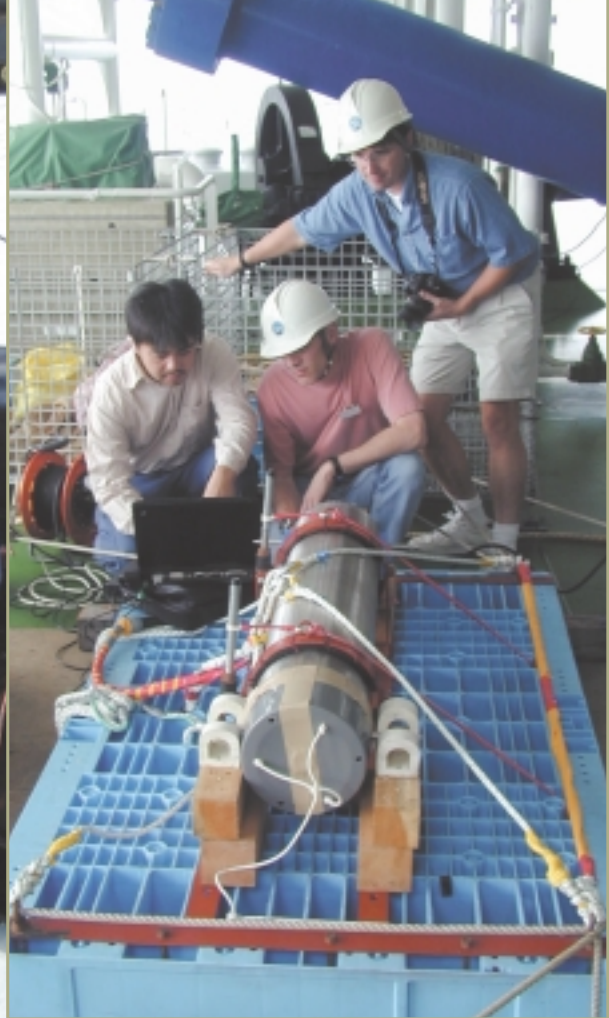
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THE DIRECTOR'S REPORT:

The Promise of Fieldwork

"IN SPITE OF THE APPARENTLY VAST ACCUMULATION OF DATA, SUCH AN IMPORTANT QUESTION AS WHETHER THE EARTH'S MAGNETIC ENERGY IS INCREASING OR DECREASING AND THE ANNUAL RATE OF CHANGE CAN NOT BE DEFINITELY ANSWERED. THE CHIEF REASON FOR THIS UNFORTUNATE STATE OF AFFAIRS IS THAT THE ACCUMULATED MATERIAL HAS NOT THE REQUIRED GENERAL DISTRIBUTION, BUT PERTAINS CHIEFLY TO CIVILIZED AND RESTRICTED LAND AREAS, LEAVING ALMOST NEGLECTED THE GREATER PART OF THE EARTH COVERED BY WATER... THERE IS HERE REVEALED TO THE INSTITUTION A MOST USEFUL AND PROMISING FIELD OF WORK."

L.A.B AUER (1904)¹

When the Department of Terrestrial Magnetism (DTM) began its work in April 1904, the guiding vision of the inaugural director, Louis Bauer, was that gaining a new understanding of the Earth's magnetic field required taking observations in areas of the globe where none had been made before. For the next quarter century, the department mounted scientific expeditions to the uncharted interior of the continents and launched ship on circumglobal voyages of measurement and discovery. Although these scientific quests in the department have changed direction many times since 1904, the principle that new insight into the workings of the Earth, the planets, or the stars often requires that our scientists venture from their laboratories to the field remains as true as in Bauer's day. As in 1904, our field areas include all of the continents, and we make use of special

facilities such as oceanographic research vessels. After nearly a century, however, our facilities now include telescopes as well as ships, and our field presence is often considerably extended by the use of robotic underwater vehicles or autonomous spacecraft.

Our seismologists now operate a total of 25 broadband portable seismometers, and the instruments are in nearly steady use, often in far-flung regions of the globe. At the end of 2001, DTM seismometers were operating in temporary networks on the Galápagos and Azores archipelagos designed to enable imaging of these seismic velocity structure of the mantle beneath the set of two active oceanic hot spots (see frontispiece montage). Another set of seismometers is in the Yunnan

¹ L.A. Bauer, "Terrestrial Magnetism," *Carnegie Year Book* No. 3, p. 70, Carnegie Institution of Washington, Washington, D.C., 1904.

Left: This montage illustrates aspects of fieldwork performed by DTM staff in the past year. (Top left) Larry Nittler is collecting a meteorite from a nice field near Meteorite Hills, Antarctica, December 2000. (Top right) DTM computer systems manager Michael Acerno (center) and electronic technician Brian Schleigh (right), along with Eiichiro Araki of the Japan Marine Science and Technology Center, are shown on the *R.V. Kaiyo* in September 2001 (photo courtesy Alan Linde). The group is testing a data-recording package prior to its installation at these a floor above a borehole instrument package in the oceanic crust on the western terrace of the Japan Trench. (Bottom) Vinicia Cácires and Gorki Vuit, both of the Escuela Politécnica Nacional in Quito, Ecuador, are servicing a broadband seismic station in a lava cave on the volcanically active island of Fernandina. The station is part of a network that DTM is operating in the Galápagos Islands in a collaborative experiment with the University of Oregon (photo courtesy Harry Oscar Wood Fellow Derek Schutt).

Province, China, as part of a cooperative U.S.-Chinese project aimed at understanding the tectonics and earthquake mechanics of the most seismically active region in that country.

The power of such experiments to yield new insight into the characteristics and evolution of large-scale Earth structure is well illustrated by recent results from the Kaapvaal Craton Project. During a two-year period from 1997 to 1999, 55 broadband seismic stations were operated at 82 sites across southern Africa. Images of mantle structure obtained by David James, Paul Silver, and colleagues during that experiment not only delineate the deep roots of the continental lithosphere (Year Book 99/00, pp. 65-66), they also demonstrate that the seismic images can be correlated with geochemical characteristics of deep mantle rocks (or xenoliths) brought to the surface by past volcanic eruptions of kimberlites in the region. As may be seen in Figure 1, the seismic velocity of the upper mantle correlates with the ages of the xenoliths inferred by Richard Carlson, Steven Shirey, and coworkers from Re/Os isotope analyses (see Year Book 93, pp. 109-117). Shirey, James, and others have also correlated mantle seismic velocity with the carbon isotopic composition, nitrogen concentration, inclusion age, and inclusion chemistry in kimberlitic diamonds. These differences in diamonds and seismic velocities appear to result from episodes of lithospheric heating and alteration by fluids subsequent to the emplacement of this ancient continental craton.

Although the Carnegie Institution no longer operates ships at sea, DTM scientists continue to make use of oceanographic vessels in their research. In 1999, from the drill ship operated by the Ocean Drilling Program, Selwyn Sacks and Alan Linde installed strainmeters and other geophysical instruments in deep boreholes near the Japan Trench. Last year the strainmeter group returned to the installation sites to replace seafloor instrument packages with the assistance of a remotely operated underwater vehicle (see frontispiece montage). To take advantage of the operation of our broadband seismic experiment in the Galápagos Islands last year, a group from

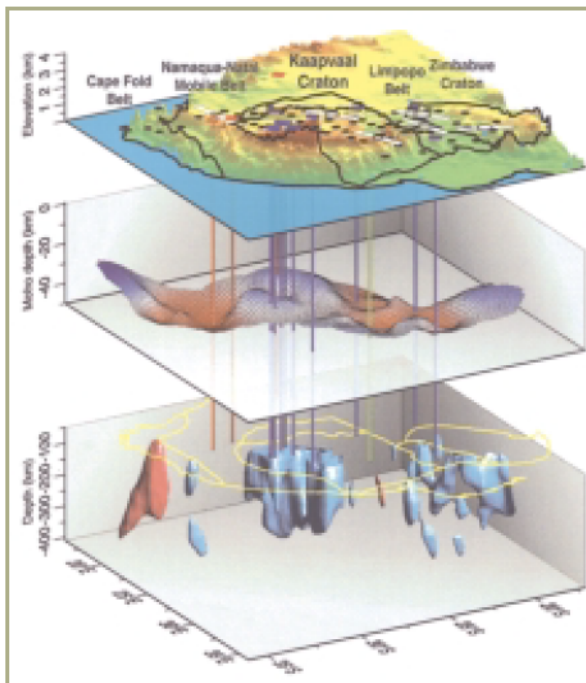


Fig. 1. DTM staff have shown that geophysical and geochemical measurements from the Kaapvaal Craton and surrounding terrain in southern Africa offer correlated and complementary constraints on the evolution of this ancient continental block. In the top panel, mapped onto a depiction of topography, are the locations of portable broadband seismic stations (black circles), an indication of the direction of fast mantle shear-wave propagation direction (white circles with white bars), geological province boundaries (black lines), and the locations of major kimberlite localities (diamonds) keyed by Re/Os model ages of mantle xenoliths (blue, > 2.5 billion years; green, 2-2.5 billion years; red, < 2 billion years). The middle panel shows the base of the continental crust, with red and blue regions denoting crust thicker and thinner than average, respectively. The bottom panel shows P-wave anomalies in the upper mantle, with red and blue denoting low- and high-velocity anomalies, respectively. Projections of geological province boundaries are shown in yellow.

the Woods Hole Oceanographic Institution and the University of Oregon carried out a seismic refraction profile from an oceanographic ship to determine the structure of the crust underlying the seafloor platform on which the islands are located. In late 1997, Steven Shirey was part of the ship-board scientific party that retrieved a densely spaced set of samples of young volcanic material (basalt glass) from the seafloor along a section of the East Pacific Rise (Fig. 2), the largest continuous volcanic feature on Earth. Shirey, together with Erik Hauri and others at DTM, is now ana-

lyzing the abundances of volatiles (F, Cl, H₂O, CO₂, and SO₂) and the isotopic signatures of light elements (Li, B) in those samples to unravel details of magma-seawater interactions, their associations with magma chamber processes, and the possible presence of recycled crust in the mantle.

Cosmochemist Larry Nittler, who joined the DTM research staff in March 2001, carries out fieldwork of a different sort. Nittler is one of the young leaders in the field of presolar grains and their links to stellar and solar system evolution. While a Carnegie Fellow at DTM during the period 1996 to 1999, Nittler developed an imaging system for the DTM ion probe, an achievement that substantially increases the rate at which meteoritic material can be searched for the isotopic anomalies diagnostic of a presolar origin (see Year Book 99/00, pp. 64-65). We extended an offer of a research staff position to Nittler in March 1999, but he had just accepted a two-year position at the NASA Goddard Space Flight Center as a member of the X-ray/Gamma-Ray Spectrometer (XGRS) team on the Near Earth Asteroid Rendezvous (NEAR) mission (see below). By mutual agreement, Nittler delayed his start at DTM so that he could learn firsthand the art of geochemical remote sensing.

Before completing his tenure at NASA Goddard, Nittler was invited to join the Antarctic Search for Meteorites (ANSMET) team for their austral summer season of 2000-2001. ANSMET, a program sponsored by the National Science Foundation, sends small teams of scientists every year to the Antarctic ice fields. While meteoroids can fall anywhere on Earth, in Antarctica the interaction of the flowing ice sheets and the underlying topography creates vast regions where stagnant ice can deflate and thus expose meteorites that had been trapped in the ice for tens of thousands of years. The dark meteorites are readily spotted on the ice surface, and in 25 years the ANSMET program has added more than 10,000 meteorites to the world's collections. Nittler's seven-person team recovered more than 700 meteorite specimens in five and a half weeks on

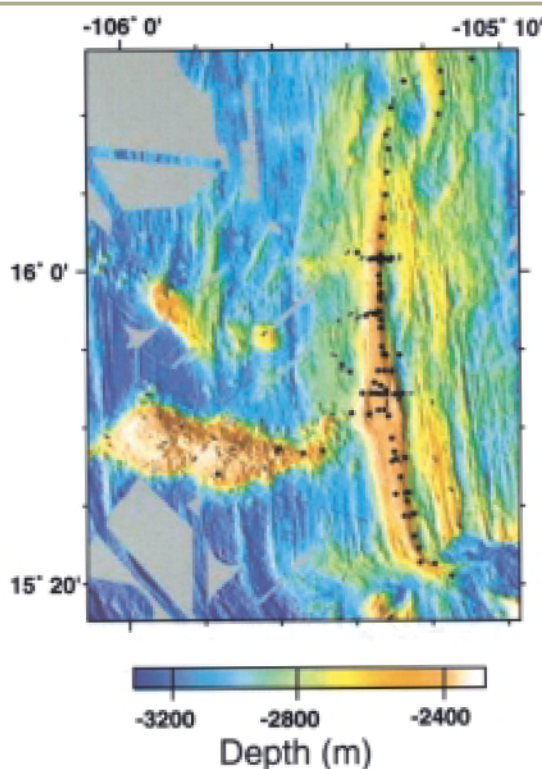


Fig. 2. DTM geochemists are studying the role of volatiles in the evolution of basalts erupted along the East Pacific Rise (EPR) near the Orozco Fracture Zone. Locations of sampling by rock coring (black dots) and dredging (black lines) are shown atop a multibeam bathymetric map of the region. The axis of the EPR is the shallow, north-south-trending feature; the shallow east-west-trending feature consists of volcanic material erupted on older, off-axis crust.

the ice (see frontispiece montage). No one on the team has any greater claim to the finds than anyone else in the scientific community, however, so participation in an ANSMET team is an act of extraordinary community service as well as an opportunity for unusual adventure.

For the DTM astronomers, their "field area" is the universe and its population of planets, stars, and galaxies. The nearest equivalent to a voyage on an oceanographic ship or a visit to an ice field is a trip to a mountaintop observatory. Vera Rubin, for instance, last year measured high-resolution spectra of low-surface-brightness (LSB) galaxies at the 4-meter telescope at Kitt Peak National

Observatory and the 6.5-meter Magellan telescope at Las Campanas. From such spectra she derived rotation curves for each galaxy. In LSB galaxies the stellar population makes only a small contribution to the total mass, so dark matter dominates the observed rotation. With former Carnegie Fellow Stacy McGaugh (now at the University of Maryland) and colleagues in Australia and France, Rubin found that the mass distribution in most LSB galaxies is dominated by a nearly constant-density core, a result that is challenging current models of cold-dark-matter cosmology.

Our most itinerant observer is surely Paul Butler, whose quest to discover and characterize extrasolar planets led him to spend a total of 43 nights last year at three telescope facilities: the 10-meter Keck telescope on Mauna Kea, the 4-meter Anglo-Australian telescope in Coonabarabran, New South Wales, and the Very Large (8-meter) Telescope of the European Southern Observatory in Paranal, Chile. Over the past year, Butler and his collaborators have announced the discovery of 15 new extrasolar planets, the second and third documented examples of multiple-planet systems, and three additional Jupiter-mass planets in circular orbits about 1-1.5 astronomical units from their parent stars (see Year Book 99/00, pp. 62-63, for mention of the first such planet to be discovered). With a variant of the radial velocity method used to detect the signature of extrasolar planets, Butler and several colleagues also reported last year the first clear detection of solarlike oscillations in a solar-mass star, opening the field of observational asteroseismology.

The DTM astronomy group witnessed several important transitions during the past year. During a leave of absence from August 2000 through August 2001, John Graham served as program director for stellar astronomy and astrophysics at the National Science Foundation. On April 1, 2001, Vera Rubin was named a Senior Fellow. On August 1, 2001, George Wetherill became Director Emeritus. A celebration marking George Wetherill's change in status was held at P Street on October 13, and a symposium honoring Vera Rubin and her work is planned for January. DTM

welcomed our newest member of the research staff, Alycia Weinberger, in July 2001.

An infrared astronomer, Alycia Weinberger (Fig. 3) studies the disks of dust and gas surrounding young stars (< 40 million years old). It is from these disks that planets potentially form. With high-resolution infrared imaging, she has documented radial gaps, warps, and other asymmetries in these disks—features that may be signatures of planets within the disks. From variations in scattered radiation, she has constrained the physical and chemical characteristics of the dust. Weinberger also makes use of infrared spectroscopy, with which she has shown that there are major chemical differences among disks studied to date, particularly in the predominance of silicates or of such carbon-based compounds as polycyclic aromatic hydrocarbons. Infrared spectroscopy is also sensitive to the presence of ices of water, methane, and ammonia, important constituents in the outer solar system. As befits her specialty, Weinberger relies on major astronomical facilities for her observations. During the last year, she made use of the Lick and Palomar Observatories in California to search for nearby



Fig. 3. Alycia Weinberger, DTM's newest Staff Member, stands in front of a model of the Hubble Space Telescope (HST) at the National Air and Space Museum. Weinberger uses the HST in her research on planetary system formation. (Courtesy the National Air and Space Museum; photo by John Strom.)

young stars and to determine the masses of young stellar binaries from their orbital motions. A portion of her work on infrared imaging and spectral characterization of disks last year was carried out at the Keck Observatory in Hawaii.

In astronomy and planetary science, another form of "fieldwork" involves space observatories or robotic explorers of solar system objects, research tools attracting the attention of an increasing fraction of the DTM staff. In her studies of disks last year, Weinberger made extensive use of instruments on the Hubble Space Telescope. She collected new data from the Space Telescope Imaging Spectrograph and analyzed archival data from the Near Infrared Camera and Multi-Object Spectrometer. Alan Boss is a member of the science team for the Kepler mission, recently selected for funding under NASA's Discovery Program. Scheduled for launch in 2006, Kepler will carry a 1-meter-diameter telescope designed to detect the stellar transits of extrasolar planets by the continuous photometric measurement of 100,000 stars. Paul Butler is a science team member for one of the Key Projects on the NASA Space Interferometry Mission, presently slated for launch in 2009. The goals of that project, led by Geoffrey Marcy of the University of California at Berkeley, include searches for planetary systems, 5 to 20 Earth-mass planets, and terrestrial planetary analogues. My own current involvement in spacecraft missions includes serving as a coinvestigator on the Mars Orbiter Laser Altimeter (MOLA) experiment aboard Mars Global Surveyor, a spacecraft that has been surveying Mars since 1997 (Fig. 4). I am also the Principal Investigator for the MESSENGER mission, scheduled to fly by and orbit Mercury after a March 2004 launch.

Larry Nittler's work on the NEAR XGRS experiment is illustrative of the ability of spacecraft observations to address important topics in solar system exploration. While there is a large body of literature on the detailed characteristics of meteorites, the vast majority of meteorites cannot be linked confidently to a specific parent body. Both orbital dynamical calculations and direct orbit reconstructions from fireball paths indicate

that most meteorites are derived from asteroids. Asteroids have been sorted into groups on the basis of their wavelength-dependent reflectance of sunlight, and meteorites have been classified on the basis of their chemistry, mineralogy, age, and isotope systematics. Deciding which meteorite types were derived from which asteroid classes, however, has proved to be a daunting challenge. It was partly with the goal in mind of addressing this question that the NEAR mission involved launching a spacecraft to orbit an asteroid, the near-Earth object 433 Eros (Fig. 5), a member of

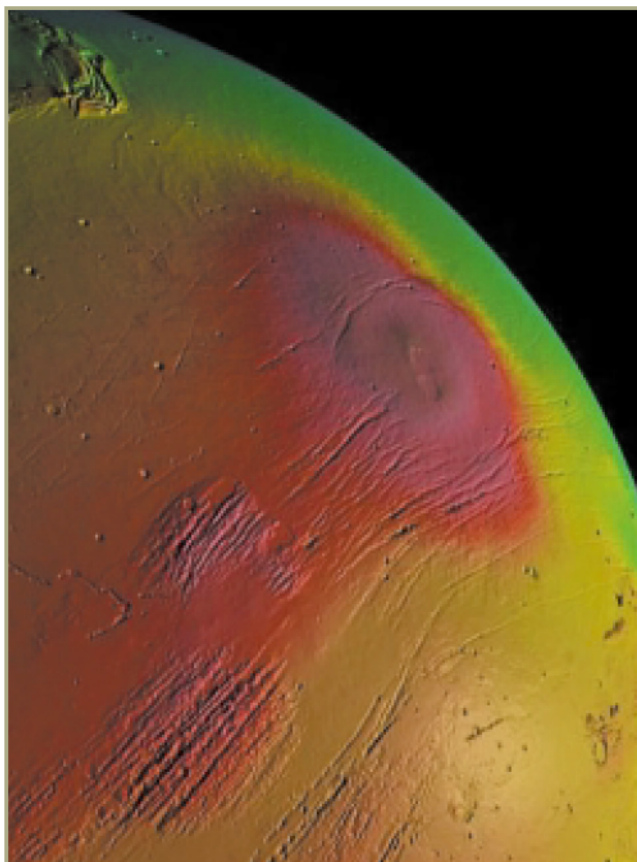


Fig. 4. This oblique view of Martian topography is centered on Alba Patera, at more than 1,000 km in diameter the largest volcano on Mars (greens, yellows, and reds denote progressively higher elevation). As demonstrated by the work of former DTM postdoctoral associate Patrick McGovern, the distribution of extensional faults, which extend from the lower left of the frame toward the upper right and onto the volcanic edifice, indicates that uplift of the volcano by intrusions or mantle processes was a major contributor to the state of stress within the edifice.

the so-called S spectral class. The NEAR Shoemaker spacecraft (renamed following the death of planetary geology pioneer Eugene Shoemaker in 1997) achieved orbit around Eros in February 2000, acquired orbital data for one Earth-year, and landed on the asteroid in February 2001. The x-ray spectrometer on the XGRS instrument measured the abundances of several major elements in the surface materials of the asteroid. For all of the measured elements except sulfur (a volatile element likely to have been depleted at the asteroid surface by space weathering processes), the composition is in agreement with those of ordinary chondrites (Fig. 6), the most common meteorites in our collections. This finding by Nittler and his colleagues substantiates a conclusion made more than 15 years ago by George Wetherill, on dynamical grounds, that the S-class asteroids—the most common objects in the inner asteroid belt—are the parent bodies for ordinary chondrites.

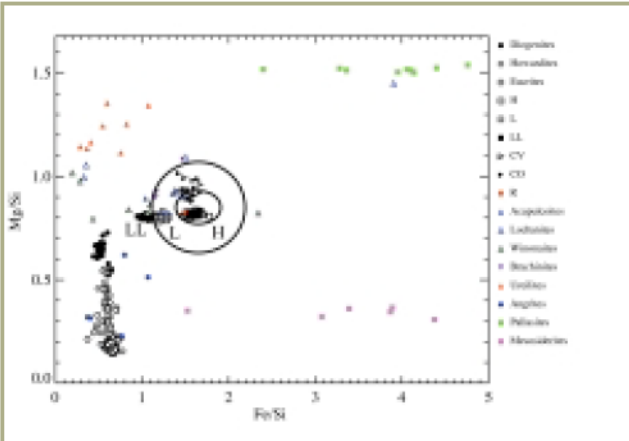


Fig. 6. Elemental ratios Mg/Si and Fe/Si, measured on 433 Eros by remote x-ray spectrometry, have been reported by Larry Nittler and his colleagues on the NEAR Shoemaker XGRS experiment. Semimajor axes of the larger ellipse equal two standard deviations in the data; those for the smaller ellipse denote twice the standard error of the mean. Shown for comparison are the same elemental ratios for several major classes of meteorites. The symbols H, L, and LL denote groups of ordinary chondrites distinguished primarily by Fe abundance.



Fig. 5. The near-Earth asteroid 433 Eros was the focus of one year of orbital observations by the NEAR Shoemaker spacecraft, which landed on the asteroid in February 2001 (photo courtesy NASA and the Johns Hopkins University Applied Physics Laboratory). The crater Psyche located in the center of the imaged portion of the asteroid is 5.3 km in diameter.



Fig. 7. Members of the Department of Terrestrial Magnetism staff are shown on November 15, 2001. First row (from left): Fouad Tera, Louis Brown, Sujoy Mukhopadhyay, Tao (Kevin) Wang, Brian Schleigh, Pablo Esparza, Maceo Bacote, Vera Rubin, Pedro Roa, Janice Dunlap, Sandra Keiser, Rosa Maria Esparza, George Wetherill, Lawrence Patrick, Ben Pandit. Second row: Steven Shirey, Terry Stahl, Petrus le Roux, Richard Carlson, Shaun Hardy, Merri Wolf, Nelson McWhorter, Mary Coder, Mary Horan, Timothy Mock, Roy Dingus, Jonathan Aurnou. Third row: James Van Orman, Sean Solomon, Alycia Weinberger, Nader Haghighipour, Steven Desch, Jianhua Wang, David James, Alan Linde, Aaron Pietruszka, Georg Bartels, John Graham. Fourth row: Alan Boss, Christopher McCarthy, Andrew Dombard, Thorsten Becker, Satoshi Inaba, Paul Butler, Conel Alexander, Hugh Van Horn, Jay Bartlett, II, Kevin Burke, Larry Nittler, Paul Silver, Roy Scalco, William Key, Gary Bors, Derek Schutt.

Although Louis Bauer was focused on a single mission for the early department, a mission now largely accomplished, his appreciation of the need to make field observations if we are to understand our planet has equal validity across the much broader spectrum of scientific questions that define the research agenda of the department today. In Earth science, planetary science, and the study of stars, extrasolar planets, and galaxies, there is no substitute for bringing the observer

closer to the object of study. Whether that action is accomplished at a telescope, on a ship, by travel to a distant expanse of rock or ice, or by the remote operation of a robotic vehicle, DTM staff will be engaged in fieldwork as an essential element of our tools of inquiry for the foreseeable future, in much the same spirit that Bauer imparted to our department's mission nearly a century before.

—Sean C. Solomon

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July 1, 2000 – June 30, 2001

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² To March 31, 2001

³ From January 1, 2001

⁴ Joint appointment with the Geophysical Laboratory

⁵ From April 1, 2001

⁶ To June 30, 2001

⁷ From September 1, 2000

⁸ To November 30, 2000

⁹ To October 22, 2000

¹⁰ From August 1, 2000

¹¹ From July 10, 2000

¹² To December 31, 2000

¹³ To April 30, 2001

¹⁴ To August 14, 2000

¹⁵ To July 31, 2000

¹⁶ From March 2, 2001

¹⁷ From April 4, 2001

¹⁸ To September 30, 2000

¹⁹ From November 13, 2000

²⁰ From September 16, 2000

²¹ To August 31, 2000

²² From July 31, 2000

²³ To April 6, 2001

²⁴ From April 18, 2001

²⁵ From September 25, 2000

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AlidaFenner, *Mentor Teacher*¹
JacquelineGoodloe, *Mentor Teacher*^{1,2}
CharlesJames, *CASE Science Coordinator*^{1,2}
CoreyKhan, *CASE Intern*²
NicholasKrump, *Mentor Teacher*¹
BrianLaMacchia, *Mentor Teacher*²
KamenMack, *CASE Intern*¹
AshaMathur, *Mentor Teacher*^{1,2}
FranMcCrackin, *Mentor Teacher*^{1,2}
KellistonMcDowell, *CASE Intern*²
SharonMusa, *Mentor Teacher*^{1,2}
BethNalker, *Mentor Teacher*¹
ThomasNassif, *Mentor Teacher*^{1,2}
MonicaNegoye, *Consultant, Mathematics Institute*^{1,2}
TiffanyRolling, *CASE Intern, First Light Assistant*^{1,2}
ChristineSills, *Mentor Teacher*²
CarolSovine, *Mentor Teacher*²
GregoryTaylor, *CASE and First Light Coordinator*^{1,2}
LindseyTaylor, *CASE Intern*²
SueP.White, *CASE Mathematics Coordinator*^{1,2}
LatishaWhitley, *CASE Intern*^{1,2}

¹ SummerInstitute2000
² SummerInstitute2001

PublicationsofthePresident

Singer,MaxineF. ,Lecturesongeneticallymodifiedplants, *Raddcliffe Quarterly*,Fall2000.

Singer,MaxineF. ,Commentary, *2001 AAAS Science and Technology Policy Yearbook*, A.H.Teich, S.D.Nelson,C.McEnaney,andS.J.Lita,eds.,AmericanAssociationfortheAdvancementof Science,2000.

Singer,MaxineF. ,Aninclusiveagendaforchange,Op-Edpage, *Washington Post*, July2,2001.

Singer,MaxineF. ,Answersfromoutsidethebox,Op-Edpage, *Washington Post*, September24, 2001.

The Capital Science Lectures are sponsored by the institution with substantial support from Burroughs Wellcome Fund, Human Genome Sciences, Inc., and the Johnson & Johnson Family of Companies. The lectures—free and open to the public—are held in the Root Auditorium at Carnegie's headquarters at 16th and P Streets in northwest Washington, D.C. Speakers also meet informally with groups of high school students. During the 2000-2001 year, the following lectures were given:

CAPITAL SCIENCE LECTURES—ELEVENTH SEASON

Searching for Life in the Universe: Lessons from the Earth, by Kenneth H. Nealson (Jet Propulsion Laboratory, Department of Geology and Environmental Science, California Institute of Technology), October 3, 2000

Extrasolar Planets: First Reconnaissance, by R. Paul Butler (Department of Terrestrial Magnetism, Carnegie Institution of Washington), October 24, 2000

The Invisible Forest: Phytoplankton and Global Change, by Sallie W. Chisholm (Department of Civil and Environmental Engineering and Department of Biology, Massachusetts Institute of Technology), November 28, 2000

Will the Universe Expand Forever? by Neta Bahcall (Department of Astrophysical Sciences, Princeton University), January 30, 2001

Beyond the Edge of the Sea: Volcanoes and Life in the Deep Ocean, by Cindy Lee Van Dover (Department of Biology, The College of William and Mary), February 27, 2001

Visual Perception: From Neural Circuits to Behavioral Decisions, by William T. Newsome (Department of Neurobiology, Howard Hughes Medical Institute, Stanford University Medical Center), March 20, 2001

Why Global Warming Is Controversial, by S. George Philander (Department of Geosciences, Princeton University), April 17, 2001

Financial Profile

Reader's Note: In this section, any discussion of spending levels or endowment amounts are on a cash or cash-equivalent basis. Therefore, the funding amounts presented do not reflect the impact of capitalization, depreciation, or other non-cash items.

The primary source of support for Carnegie Institution of Washington's activities continues to be its endowment. This reliance has led to an important degree of independence in the research program of the institution. This independence is anticipated to continue as a mainstay of Carnegie's approach to science in the future.

At June 30, 2001, the endowment was valued at approximately \$512.0 million and had a total return (net of management fees) of 10.6%. The annualized five-year return for the endowment was 13.1%.

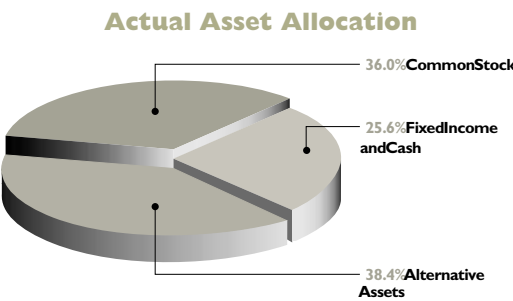
For a number of years, Carnegie's endowment has been allocated among a broad spectrum of asset classes. This includes fixed-income instruments (bonds), equities (stocks), absolute return investments, real estate partnerships, private equity, an oil and gas partnership, and a hedge fund. The goal of diversifying the endowment into alternative assets is to reduce the volatility inherent in an undiversified portfolio while generating attractive overall performance.

In its private equity allocation, the institution accepts a higher level of risk in exchange for a higher return. By entering into real estate partnerships, the institution in effect, holds part of its endowment in high-quality commercial real estate, deriving both capital appreciation and income in the form of rent from tenants. Along with the oil and gas partnership, this asset class provides an effective hedge against inflation. Finally, through its investments in an absolute return partnership and a hedge fund, the institution seeks to achieve long-term returns similar to those of traditional U.S. equities with reduced volatility and risk.

The finance committee of the board regularly examines the asset allocation of the endowment and readjusts the allocation, as appropriate. The institution relies upon external managers and partnerships to conduct the investment activities, and it employs a commercial bank to maintain custody.

The following chart shows the allocation of the institution's endowment among the asset classes it uses as of June 30, 2001:

	Target Allocation	Actual Allocation
Common Stock	35%	36.0%
Alternative Assets	40%	38.4%
Fixed Income and Cash	25%	25.6%



Carnegie's primary purpose is to maintain the long-term spending power of its endowment. To achieve this objective, it employs a budgeting methodology that provides for:

- averaging the total market value of the endowment for the three most recent fiscal years, and
- developing a budget that spends at a set percentage (spending rate) of this three-year market average.

During the 1990s, this budgeted spending rate has been declining in a phased reduction, moving towards an informal goal of a spending rate of 4.5%. For the 2000-2001 fiscal year, the rate was budgeted at 5.3%. While Carnegie has been reducing this budgeted rate by between 5 and 10 basis points a year, there has also been continuing, significant growth in the size of the endowment.

Carnegie Funds Spending Over Seven Years

(Dollars in Millions)

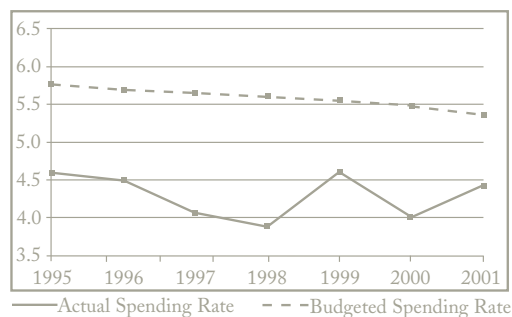
FY	94-95	95-96
Carnegie Funds Spending	\$ 13.9	\$ 15.1
Actual Market Value at June 30	\$304.5	\$338.0
Actual Spending as % of Market Value	4.57%	4.48%
Planned Spending Rate in Budget	5.76%	5.71%

The result has been that, for the 2000-2001 fiscal year, the actual spending rate (the ratio of annual spending from the endowment to actual endowment value at the conclusion of the fiscal year in which the spending took place) was 4.45%.

The table at the bottom compares the planned versus the actual spending rates, as well as the market value of the endowment from 1994-1995 to the most recently concluded fiscal year, 2000-2001.

The following chart compares the planned versus the actual spending rates, as well as the market value of the endowment from 1994-1995 to the most recently concluded fiscal year, 2000-2001:

Budget and Actual Spending Rates



Within Carnegie's endowment, there are a number of "Funds" that provide support either in a general way or in a targeted way, with a specific, defined purpose. The largest of these is the Andrew Carnegie Fund, begun with the original gift of \$10 million. Mr. Carnegie later made additional gifts totaling another \$12 million during his lifetime. Together these gifts are now valued at over \$412 million.

UNAUDITED

The following Table shows the amounts in the principal funds within the institution's endowment as of June 30, 2001.

Market value of the Principal Funds Within Carnegie's Endowment

AndrewCarnegie	\$411,934,769
CapitalCampaign	35,822,182
MellonMatching	10,996,150
AstronomyFunds	8,471,035
AnonymousMatching	8,235,757
Anonymous	8,151,476
Wood	5,703,698
Golden	3,633,483
CarnegieFutures	3,467,491
Bowen	2,701,734
Colburn	2,174,096
ScienceEducationFund	2,102,490
McClintockFund	1,717,433
SpecialInstrumentation	1,201,473
BushBequest	1,109,997
MoseleyAstronomy	848,821
StarrFellowship	821,252
SpecialOpportunities	792,487
Roberts	458,352
Lundmark	351,393
Morgenroth	264,957
Hollaender	251,447
Moseley	152,702
Forbush	150,887
Bush	121,522
GreenFellowship	114,570
Hale	105,165
Harkavy	104,011

Total	\$511,960,830
-------	---------------

96-97	97-98	98-99	99-00	00-01
\$ 15.5	\$ 16.4	\$ 20.9	\$ 20.0	\$22.8
\$382.9	\$423.3	\$451.6	\$477.9	\$512.0
4.05%	3.87%	4.63%	4.18%	4.45%
5.66%	5.61%	5.50%	5.40%	5.30%

Financial Statements

for the year ended June 30, 2001

*Independent Auditors' Report**To the Audit Committee of the
Carnegie Institution of Washington:*

We have audited the accompanying statements of financial position of the Carnegie Institution of Washington (Carnegie) as of June 30, 2001 and 2000, and the related statements of activities and cash flows for the years then ended. These financial statements are the responsibility of Carnegie's management. Our responsibility is to express an opinion on these financial statements based on our audits.

We conducted our audits in accordance with auditing standards generally accepted in the United States of America. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation. We believe that our audits provide a reasonable basis for our opinion.

In our opinion, the financial statements referred to above present fairly, in all material respects, the financial position of the Carnegie Institution of Washington as of June 30, 2001 and 2000, and its changes in net assets and its cash flows for the years then ended, in conformity with accounting principles generally accepted in the United States of America.

Our audits were made for the purpose of forming an opinion on the basic financial statements taken as a whole. The supplementary information included in Schedule I is presented for purposes of additional analysis and is not a required part of the basic financial statements. Such information has been subjected to the auditing procedures applied in the audits of the basic financial statements and, in our opinion, is fairly presented in all material respects in relation to the basic financial statements taken as a whole.

KPMG LLP

Washington, D.C.
October 26, 2001

Statements of Financial Position

June 30, 2001 and 2000

Assets	2001	2000
Cash and cash equivalents	\$1, 370,838	2,813,503
Accrued investment income	123,789	122,379
Contributions receivable (note 2)	10,042,248	2,300,913
Accounts receivable and other assets	4,188,572	4,054,197
Bond proceeds held by trustee (note 6)	392	214,384
Investments (note 3)	517,305,413	487,191,642
Construction in progress (notes 4 and 5)	34,026,765	67,419,680
Property and equipment, net (note 4)	87,165,558	46,310,015
	\$ 654,223,575	610,426,713

Liabilities and Net Assets

Accounts payable and accrued expenses	\$5, 676,804	4,576,061
Deferred revenue (note 5)	33,048,536	33,076,609
Bonds payable (note 6)	34,917,054	34,880,190
Accrued postretirement benefits (note 7)	10,497,000	10,321,000
Total liabilities	84,139,394	82,853,860
Net assets (note 8):		
Unrestricted:		
Board designated:		
Invested in fixed assets, net	53,226,733	45,772,896
Designated for managed investments	452,200,043	424,925,680
Undesignated	5,238,854	1,594,787
	510,665,630	472,293,363
Temporarily restricted	21,655,218	17,575,634
Permanently restricted	37,763,333	37,703,856
Total net assets	570,084,181	527,572,853
Commitments and contingencies (notes 10, 11, and 12)		
Total liabilities and net assets	\$ 654,223,575	610,426,713

See accompanying notes to financial statements.

Statements of Activities

Years ended June 30, 2001 and 2000

	2001				2000			
	Unrestricted	Temporarily restricted	Permanently restricted	Total	Unrestricted	Temporarily restricted	Permanently restricted	Total
Revenues and support:								
Grants and contracts	\$18,210,545	—	—	18,210,545	15,945,496	—	—	15,945,496
Contributions and gifts	9,112,683	4,469,725	2,673	13,585,081	503,000	3,429,115	12,577	3,944,692
Net gain (loss) on disposal of property	19,449	—	—	19,449	(30,763)	—	—	(30,763)
Other income	1,211,623	—	—	1,211,623	1,556,603	—	—	1,556,603
Net external revenue	28,554,300	4,469,725	2,673	33,026,698	17,974,336	3,429,115	12,577	21,416,028
Investment income (note 3)	49,106,316	2,475,765	56,804	51,638,885	45,028,935	2,314,107	51,931	47,394,973
Net assets released from restrictions (note 8)	2,865,906	(2,865,906)	—	—	4,727,863	(4,727,863)	—	—
Required net asset transfers (note 9)	—	—	—	—	(2,557,581)	2,557,581	—	—
Total revenues, gains, and other support	80,526,522	4,079,584	59,477	84,665,583	65,173,553	3,572,940	64,508	68,811,001
Program and supporting services expenses:								
Terrestrial Magnetism	7,238,422	—	—	7,238,422	6,677,062	—	—	6,677,062
Observatories	7,819,566	—	—	7,819,566	7,387,676	—	—	7,387,676
Geophysical Laboratory	8,039,808	—	—	8,039,808	8,005,144	—	—	8,005,144
Embryology	6,421,919	—	—	6,421,919	6,334,585	—	—	6,334,585
Plant Biology	7,864,699	—	—	7,864,699	6,082,263	—	—	6,082,263
Other Programs	1,121,442	—	—	1,121,442	588,972	—	—	588,972
Administrative and general expenses	3,648,399	—	—	3,648,399	3,079,513	—	—	3,079,513
Total expenses	42,154,255	—	—	42,154,255	38,155,215	—	—	38,155,215
Increase in net assets	38,372,267	4,079,584	59,477	42,511,328	27,018,338	3,572,940	64,508	30,655,786
Net assets at the beginning of the year	472,293,363	17,575,634	37,703,856	527,572,853	445,275,025	14,002,694	37,639,348	496,917,067
Net assets at the end of the year	\$510,665,630	21,655,218	37,763,333	570,084,181	472,293,363	17,575,634	37,703,856	527,572,853

See accompanying notes to financial statements.

Statements of Cash Flows

Years ended June 30, 2001 and 2000

	2001	2000
Cash flows from operating activities:		
Increase in net assets	\$42,511,328	30,655,786
Adjustment to reconcile increase in net assets to net cash provided by (used for) operating activities:		
Depreciation	3,998,845	3,338,544
Net gain on investments	(39,212,556)	(36,146,464)
Loss (gain) on disposal of property	(19,449)	30,763
Amortization of bond issuance costs and discount	36,864	36,865
Contribution of stock	(915,587)	(1,042,453)
(Increase) decrease in assets:		
Receivables	(7,875,710)	(138,799)
Accrued investment income	(1,410)	415,091
Increase (decrease) in liabilities:		
Accounts payable and accrued expenses	1,100,575	1,679,439
Deferred revenue	(28,073)	7,599,654
Accrued postretirement benefits	176,168	352,457
Contributions and investment income restricted for long-term investment	(3,346,804)	(1,394,599)
Net cash provided by (used for) operating activities	(3,575,809)	5,386,284
Cash flows from investing activities:		
Draws from bond proceeds held by trustee	213,992	1,451,006
Acquisition of property and equipment	(3,176,532)	(4,378,089)
Construction of telescope, facilities, and equipment	(8,314,728)	(13,363,039)
Investments purchased	(187,658,065)	(400,648,495)
Proceeds from investment sold or matured	197,672,437	412,691,374
Proceeds from sale of property and equipment	49,236	32,166
Net cash used for investing activities	(1,213,660)	(4,215,077)
Cash flows from financing activities—proceeds from contributions and investment income restricted for:		
Investment in endowment	366,540	98,266
Investment in property and equipment	2,980,264	1,296,333
Net cash provided by financing activities	3,346,804	1,394,599
Net increase (decrease) in cash and cash equivalents	(1,442,665)	2,565,806
Cash and cash equivalents at the beginning of the year	2,813,503	247,697
Cash and cash equivalents at the end of the year	\$1,370,838	2,813,503
Supplementary cash flow information		
Cash paid for interest	\$1,397,188	1,562,611

See accompanying notes to financial statements.

Notes to Financial Statements

June 30, 2001 and 2000

(1) Organization and Summary of Significant Accounting Policies

Organization

The Carnegie Institution of Washington (Carnegie) conducts advanced research and training in the sciences. It carries out its scientific work in five research centers located throughout the United States and at an observatory in Chile. The centers are the Departments of Embryology, Plant Biology, and Terrestrial Magnetism, the Geophysical Laboratory, and the Observatories (astronomy). Income from investments represents approximately 61 and 69 percent of Carnegie's total revenues for the years ended June 30, 2001 and 2000, respectively. Carnegie's other income is mainly from gifts and federal grants and contracts.

Basis of Accounting and Presentation

The financial statements are prepared on the accrual basis of accounting. Contributions and gifts revenues are classified according to the existence or absence of donor-imposed restrictions. Also, satisfaction of donor-imposed restrictions are reported as releases of restrictions in the statements of activities.

Investments and Cash Equivalents

Carnegie's debt and equity investments are reported at their fair values based on quoted market prices. Carnegie reports investments in limited partnerships at fair value as determined and reported by the general partners. All changes in fair value are recognized in the statements of activities. Carnegie considers all highly liquid debt instruments purchased with remaining maturities of 90 days or less to be cash equivalents. Money market and other highly liquid instruments held by investment managers are reported as investments.

Income Taxes

Carnegie is exempt from federal income tax under Section 501(c)(3) of the Internal Revenue Code (the Code). Accordingly, no provision for income taxes is reflected in the accompanying financial statements. Carnegie is also an educational institution within the meaning of Section 170(b)(1)(A)(ii) of the Code. The Internal Revenue Service has classified Carnegie as other than a private foundation, as defined in Section 509(a) of the Code.

Fair Value of Financial Instruments

Financial instruments of Carnegie include cash equivalents, receivables, investments, bond proceeds held by trustee, accounts and broker payables, and bonds payable. The fair value of investments in debt and equity securities is based on quoted market prices. The fair value of investments in limited partnerships is based on information provided by the general partners.

The fair value of Series A bonds payable is based on quoted market prices. The fair value of Series B bonds payable is estimated to be the carrying value, since these bonds bear adjustable market rates.

The fair values of cash equivalents, receivables, bond proceeds held by trustee, and accounts and broker payables approximate their carrying values based on their short maturities.

Use of Estimates

The preparation of financial statements in conformity with accounting principles generally accepted in the United States of America requires management to make estimates and assumptions that affect the reported amounts of assets and liabilities and disclosure of contingent assets and liabilities at the date of the financial statements. They also affect the reported amounts of revenues and expenses during the reporting period. Actual results could differ from those estimates.

Property and Equipment

Carnegie capitalizes at cost expenditures for land, buildings and leasehold improvements, telescopes, scientific and administrative equipment, and projects in progress. Routine replacement, maintenance, and repairs are charged to expense.

Depreciation is computed on a straight-line basis over the following estimated useful lives:

Buildings and telescopes	50 years
Leasehold improvements	lesser of 25 years or the remaining term of the lease
Scientific and administrative equipment	2-10 years, based on scientific life of equipment

Contributions

Contributions are classified based on the existence or absence of donor-imposed restrictions. Contributions and net assets are classified as follows:

Unrestricted – includes all contributions received without donor-imposed restrictions on use or time.

Temporarily restricted – includes contributions with donor-imposed restrictions as to purpose of gift or time period expended.

Permanently restricted – generally includes endowment gifts in which donors stipulated that the corpus be invested in perpetuity. Only the investment income generated from endowments may be spent. Certain endowments require that a portion of the investment income be reinvested in perpetuity.

Gifts of long-lived assets, such as buildings or equipment, are considered unrestricted when placed in service. Cash gifts restricted for investment in long-lived assets are released from restriction when the asset is acquired or as costs are incurred for asset construction.

Grants

Carnegie records revenues on grants from federal agencies only to the extent that reimbursable expenses are incurred. Accordingly, funds received in excess of reimbursable expenses are recorded as deferred revenue, and expenses in excess of reimbursements are recorded as accounts receivable. Reimbursement of indirect costs is based upon provisional rates which are subject to subsequent audit by Carnegie's federal cognizant agency, the National Science Foundation.

Allocation of Costs

The costs of providing programs and supporting services have been summarized in the statements of activities. Accordingly, certain costs have been allocated among the programs and supporting services benefited.

(2) Contributions Receivable

Contributions receivable representing unconditional promises expected to be collected are summarized as follows at June 30, 2001 and 2000:

Years ending June 30,	2001	2000
2001	\$ —	1,081,084
2002	3,333,538	866,506
2003	3,277,126	322,619
2004	2,631,075	10,000
2005	1,654,000	10,000
2006	601,000	—
2007 and after	17,653	142,518
	11,514,392	2,432,727
Less discount to present value	(1,472,144)	(131,814)
	\$10,042,248	2,300,913

Pledges receivable as of June 30, 2001 and 2000, were discounted using the 10-year U.S. Treasury rate, which was approximately 6 percent.

(3)Investments

At June 30, 2001 and 2000, investments at fair value consisted of the following:

	2001	2000
Time deposits and money market funds	\$23,826,461	15,508,894
Debt mutual funds	576,479	2,762,469
Debt securities	120,546,768	113,318,084
Equity securities	161,841,511	158,985,492
Limited real estate partnerships	50,388,134	55,524,337
Limited partnerships	160,126,060	141,092,366
	\$517,305,413	487,191,642

Investment income for the years ended June 30, 2001 and 2000, consisted of the following:

	2001	2000
Interest and dividends	\$13,529,082	12,442,821
Net realized gains	13,059,771	41,174,031
Net unrealized (losses) gains	26,152,786	(5,027,567)
Less—investment management expenses	(1,102,754)	(1,194,312)
	\$51,638,885	47,394,973

As of June 30, 2001, the fair value for approximately \$80 million of Carnegie’s \$210 million of real estate and limited partnership investments has been estimated by the general partners in the absence of readily ascertainable values as of that date. However, these estimated fair values may differ from the values that would have been used had a ready market existed. As of June 30, 2000, the fair value for approximately \$179 million of Carnegie’s \$197 million of real estate and limited partnership investments had been estimated.

(4)Property and Equipment

At June 30, 2001 and 2000, property and equipment placed in service consisted of the following:

	2001	2000
Buildings and improvements	\$44,397,020	44,314,395
Scientific equipment	21,559,202	19,028,773
Telescopes	49,618,468	7,910,825
Administrative equipment	2,803,185	2,532,683
Land	787,896	787,896
Art	40,192	34,067
	119,205,963	74,608,639
Less accumulated depreciation	(32,040,405)	(28,298,624)
	\$87,165,558	46,310,015

At June 30, 2001 and 2000, construction in progress consisted of the following:

	2001	2000
Telescope	\$26,506,416	62,237,190
Buildings	398,602	352,271
Scientific equipment	7,121,747	4,830,219
	\$34,026,765	67,419,680

At June 30, 2001 and 2000, approximately \$78 million and \$71 million, respectively, of construction in progress and other property, net of accumulated depreciation, was located in Las Campanas, Chile. During 2001 and 2000, Carnegie capitalized interest costs (net of interest earned of \$3,200 and \$49,000, respectively) of approximately \$1,596,000 and \$1,514,000, respectively, as construction in progress.

(5)Magellan Consortium

During the year ended June 30, 1998, Carnegie entered into an agreement (Magellan Agreement) with four universities establishing a consortium to build and operate the Magellan telescopes. The two Magellan telescopes are located on Manqui Peak, Las Campanas in Chile. The first telescope with a cost of approximately \$41,708,000 was placed in service during 2001 while the other continues to be

built. The total construction cost of the two telescopes is expected to be approximately \$72 million and the telescopes are recorded as assets by Carnegie. Title to the Magellan facilities is held by Carnegie. As of June 30, 2001, construction in progress of \$26,506,416 related to the Magellan project.

The university members of the consortium, by contribution to the construction and operating costs of Magellan, acquire rights of access and oversight as described in the Magellan Agreement. Total contributions by the university members for construction are expected to be \$36 million, 50 percent of the total expected costs and these monies are being used by Carnegie to finance part of the Magellan Telescopes' construction costs. As of June 30, 2001 and 2000, the excess of university members contributions over operating costs totaled \$32,285,383 and \$32,717,849, respectively, and is included in deferred revenue in the accompanying statements of financial position. The deferred revenue will be recognized ratably as income over the remaining estimated useful lives of the telescopes once consortium use begins.

(6) Bonds Payable

On November 1, 1993, Carnegie issued \$17.5 million each of secured Series A and Series B California Educational Facilities Authority Revenue tax-exempt bonds. Bond proceeds are used to finance the Magellan telescope project and the renovation of the facilities of the Observatories at Pasadena. The balances outstanding at June 30, 2001 and 2000, on the Series A issue totaled \$17,448,600 and \$17,425,757, respectively, and on the Series B issue totaled \$17,468,454 and \$17,454,433, respectively. The balances outstanding are net of unamortized bond issue costs and bond discount. Bond proceeds held by the trustee and unexpended at June 30, 2001 and 2000, totaled \$392 and \$214,384, respectively.

Series A bonds bear interest at 5.6 percent payable in arrears semiannually on each April 1 and October 1 and upon maturity on October 1, 2023. Series B bonds bear interest at variable money market rates (ranging from 2.65 percent to 3.0 percent at June 30, 2001) in effect from time to time, up to a maximum of 12 percent over the applicable money

market rate period of between one and 270 days and have a stated maturity of October 1, 2023. At the end of each money market rate period, Series B bondholders are required to offer the bonds for repurchase at the applicable money market rate. If repurchased, the Series B bonds would be resold at the current applicable money market rate and for a new rate period.

Carnegie is not required to repay the Series A and B bonds until the October 1, 2023, maturity date, and Carnegie has the intent and the ability to effect the purchase and resale of the Series B bonds through a tender agent; therefore all bonds payable are classified as long term. Sinking fund redemptions begin in 2019 in installments for both series. The fair value of Series A bonds payable at June 30, 2001 and 2000, based on quoted market prices is estimated at \$18,417,000 and \$17,414,000, respectively. The fair value of Series B bonds payable at June 30, 2001 and 2000, is estimated to approximate carrying value as the mandatory tender dates on which the bonds are repriced are generally within three months of year end.

(7) Employee Benefit Plans

Retirement Plan

Carnegie has a noncontributory, defined contribution, money-purchase retirement plan in which all U.S. personnel are eligible to participate. After one year's participation, an individual's benefits are fully vested. The Plan has been funded through individually owned annuities issued by Teachers' Insurance and Annuity Association (TIAA) and College Retirement Equities Fund (CREF). Contributions made by Carnegie totaled approximately \$2,458,000 and \$2,195,000 for the years ended June 30, 2001 and 2000, respectively.

Postretirement Benefits Plan

Carnegie provides postretirement medical benefits to all employees who retire after age 55 and have at least ten years of service. Cash payments made by Carnegie for these benefits totaled approximately \$454,000 and \$382,000 for the years ended June 30, 2001 and 2000, respectively.

The expense for postretirement benefits for the years ended June 30, 2001 and 2000, consists of the following:

	2001	2000
Service costs – benefits earned during the year	\$285,000	250,000
Interest cost on projected benefit obligation	515,000	574,000
Amortization of gain	(170,000)	(89,000)
Accrued postretirement benefit cost	\$ 630,000	735,000

The 2001 postretirement benefits expense was approximately \$176,000 more than the cash expense of \$454,000, and the 2000 postretirement benefits expense was approximately \$353,000 more than the cash expense of \$382,000. The postretirement benefits expense was allocated among program and supporting services expenses in the statements of activities.

The reconciliation of the Plan’s funded status to amounts recognized in the financial statements at June 30, 2001 and 2000 follows:

	2001	2000
Changes in benefit obligation:		
Benefit obligations at beginning of year	\$6,606,000	7,848,000
Service cost	285,000	250,000
Interest cost	515,000	574,000
Actuarial loss (gain)	620,000	(1,684,000)
Benefits paid	(454,000)	(382,000)
Benefit obligation at end of year	7,572,000	6,606,000
Change in plan assets:		
Fair value of plan assets at beginning of year	—	—
Actual return on plan assets	—	—
Contribution to plan	454,000	382,000
Benefits paid	(454,000)	(382,000)
Fair value of plan assets at beginning of year	—	—
Funds status	(7,572,000)	(6,606,000)
Unrecognized net actuarial gain	(2,925,000)	(3,715,000)
Accrued benefit cost	\$(10,497,000)	(10,321,000)

The present value of the benefit obligation as of June 30, 2001, was determined using an assumed health care cost trend rate of 8.4 percent and an assumed discount rate of 7.5 percent. The present value of the benefit obligation as of June 30, 2000, was determined using an assumed health care cost trend rate of 8.7 percent and an assumed discount rate of 8.0 percent. Carnegie’s policy is to fund postretirement benefits as claims and administrative fees are paid.

For measurement purposes, an 8.4 percent annual rate of increase in the per capita cost of covered health care benefits was assumed for 2001; the rate was assumed to decrease gradually to 5.5 percent in 10 years and remain at that level thereafter. The health care cost trend rate assumption has a significant effect on the amounts reported. A one-percent-age change in assumed annual health care cost trend rate would have the following effects:

	One-percentage point increase	One-percentage point decrease
Effect on total of service and interest cost components	\$160,000	(124,000)
Effect on postretirement benefit obligation	1,231,000	(938,000)

(8) Net Assets

At June 30, 2001 and 2000, temporarily restricted net assets were available to support the following donor-restricted purposes:

	2001	2000
Specific research programs	\$16,060,208	11,845,001
Equipment acquisition and construction	5,595,010	5,730,633
	\$21,655,218	17,575,634

At June 30, 2001 and 2000, permanently restricted net assets consisted of permanent endowments, the income from which is available to support the following donor-restricted purposes:

	2001	2000
Specific research programs	\$14,558,614	14,499,137
Equipment acquisition and construction	1,204,719	1,204,719
General support (Carnegie endowment)	22,000,000	22,000,000
	\$37,763,333	37,703,856

During 2001 and 2000, Carnegie met donor-imposed requirements on certain gifts and, therefore, released temporarily restricted net assets as follows:

	2001	2000
Specific research programs	\$2,406,098	2,608,271
Equipment acquisition and construction	459,808	2,119,592
	\$2,865,906	4,727,863

(9) Required Net Asset Transfers

During 2000, it was discovered that certain temporarily restricted net assets were released when amounts were spent on purposes other than those for which they were restricted. An amount of \$2,557,581 was reclassified to temporarily restricted net assets to be used for equipment acquisition and construction.

(10) Federal Grants and Contracts

Costs charged to the federal government under cost-reimbursement grants and contracts are subject to government audit. Therefore, all such costs are subject to adjustment. Management believes that adjustments, if any, would not have a significant effect on the financial statements.

(11) Commitments

Carnegie entered into a contract with the University of Arizona for the construction of the primary mirror and support system for the second telescope in the Magellan project. The amount of the contract is approximately \$9,700,000 of which approximately \$500,000 had not been incurred at June 30, 2001. Carnegie also has other contracts relating to the construction of Magellan with outstanding commitments totaling approximately \$161,000.

Carnegie has outstanding commitments to invest approximately \$57 million in limited partnerships.

(12) Lease Arrangements

Carnegie leases a portion of the land it owns in Las Campanas, Chile, to other organizations. These organizations have built and operate telescopes on the land. Most of the lease arrangements are not specific and some are at no-cost to the other organizations. One of the lease arrangements is noncancelable and had annual rent of approximately \$131,000 for fiscal year 2001 and annual future rent of \$160,000 through 2002. For the no-cost leases, the value of the leases could not be determined and is not considered significant and, accordingly, contributions have not been recorded in the financial statements.

Carnegie also leases a portion of one of its laboratories to another organization for an indefinite term. Rents to be received under the agreement are approximately \$480,000 annually, adjusted for CPI increases.

Carnegie leases land and buildings. The monetary terms of the leases are considerably below fair value, however, these terms were developed considering other non-monetary transactions between Carnegie and the lessors. The substance of the transactions indicates arms-length terms between Carnegie and the lessors. The monetary value of the leases could not be determined and has not been recorded in the financial statements.

Schedules of Expenses

Schedule 1

Years ended June 30, 2001 and 2000

	2001			2000		
	Carnegie funds	Federal and private grants	Total expenses	Carnegie funds	Federal and private grants	Total expenses
Personnel costs:						
Salaries	\$12,816,467	4,624,046	17,440,513	11,980,869	4,079,575	16,060,444
Fringe benefits and payroll taxes	3,912,937	1,261,398	5,174,335	3,853,256	1,097,345	4,950,601
Total personnel costs	16,729,404	5,885,444	22,614,848	15,834,125	5,176,920	21,011,045
Fellowship grants and awards	1,500,162	588,585	2,088,747	1,500,720	586,825	2,087,545
Depreciation	3,998,855	—	3,998,855	3,338,544	—	3,338,544
General expenses:						
Educational and research supplies	1,481,157	3,882,931	5,364,088	1,543,865	1,635,104	3,178,969
Building maintenance and operation	2,306,653	535,549	2,842,202	2,256,008	455,076	2,711,084
Travel and meetings	1,136,927	479,217	1,616,144	853,789	462,310	1,316,099
Publications	48,218	50,292	98,510	46,442	71,725	118,167
Shop	169,243	16,791	186,034	77,324	29,374	106,698
Telephone	190,580	13,295	203,875	195,489	10,915	206,404
Books and subscriptions	289,686	—	289,686	270,265	—	270,265
Administrative and general	769,077	112,293	881,370	170,443	790,186	960,629
Printing and copying	202,555	—	202,555	97,680	—	97,680
Shipping and postage	179,520	21,597	201,117	182,407	40,596	223,003
Insurance, taxes and professional fees	1,067,029	122,377	1,189,406	965,820	113,738	1,079,558
Equipment	2,172,131	1,450,468	3,622,599	—	2,768,276	2,768,276
Fund-raising expense	349,449	—	349,449	383,255	—	383,255
Total general expenses	10,362,225	6,684,810	17,047,035	7,042,787	6,377,300	13,420,087
Total direct costs	32,590,646	13,158,839	45,749,485	27,716,176	12,141,045	39,857,221
Indirect costs—grants	(5,051,706)	5,051,706	—	(3,804,451)	3,804,451	—
Total costs	27,538,940	18,210,545	45,749,485	23,911,725	15,945,496	39,857,221
Capitalized scientific equipment	(2,301,093)	(1,294,137)	(3,595,230)	—	(1,702,006)	(1,702,006)
Total expenses	\$ 25,237,847	16,916,408	42,154,255	23,911,725	14,243,490	38,155,215

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